PHYSICAL AND CHEMICAL CHARACTERISTICS INTERPRETATION FOR GROUNDWATER QUALITY ASSESSMENT IN THE COASTAL AREA, NORTH KELANTAN, MALAYSIA

(Interpretasi Karakterisasi Fisika dan Kimia Untuk Penilaian Kualitas Airtanah di Area Pesisir, Kelantan Utara, Malaysia)

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Abstract

Physical and chemical groundwater interpretation has been done in order to characterize and assess its associated problem in the coastal area, North Kelantan, Malaysia. A total of thirty three groundwater samples that consisted of sixteen groundwater samples were collected directly from existing well and together with seventeen groundwater data obtained from government agency, were used in this study. The depth of groundwater sample was varied from the shallow (3.5 m) to the deeper (130 m) aquifer. The physical groundwater characteristics were measured directly at the site just after the groundwater collected. The chemical content of the groundwater sample were analysed using Ion Chromatography (IC) and Inductively Coupled Plasma (ICP). Finally the data was presented and interpreted using the bivariate and piper diagram to improve interpretation and analysis of the whole data. Analysis result of the groundwater sample indicates that the shallow aquifer can be categorized as fresh water. In the zone with marine soil deposit, chloride and sulphate concentration tend to be higher in the water sample. However, the concentration of water sample is still within the accepted limit for human consumption. In places with relatively higher usage of chemical fertilizer, the groundwater sample exhibits higher nitrate concentration more than limit of safe for human consumption (>45 mg/L). K, Ca, Mg and Na content have a positive correlation with chloride concentration in deeper aquifer, indicating that the ions are derived from the same source of saline waters. The relationship between Cl/HCO_3 ratios and chloride also shows that the fresh groundwater and seawater mixing in aquifer, and the samples with lower ratios can be categorized as fresh waters. In the shallow aquifer most ions exhibit a poor correlation to chloride indicating that such ions are derived from a different source.

Keywords: aquifer, contamination, groundwater, hydrogeochemical, physical property.

Abstrak

Interpretasi karakter fisika dan kimia air tanah telah dilakukan untuk menilai kualitas air tanah dan masalah masalah yang berhubungan dengannya di zona pesisir, Kelantar Utara, Malaysia. Sebanyak tiga puluh tiga sampel airtanah yang terdiri dari enam belas sampee airtanah yang di ambil langsung dari sumur dan bersama dengan tujuh belas data sampel airtanah diperoleh dari agensi pemerintah digunakan pada penelitian ini. Kedalaman air tanah bervariasi dari yang akuifer dangkal (3,5 m) sampai ke yang dalam (130 m). Karakter fisika air tanah di ukur secara langsung di lokasi saat setelah air tanah di ambil. Kandungan kimia sampel air tanah dianalisa dengan menggunakan Ion Chromatography (IC) and Inductively Coupled Plasma (ICP). Data-data yang diperoleh di presentasikan dan diinterpretasi menggunakan diagram bivariate dan diagram piper untuk meningkatkan interpretasi dan analisa data secara keseluruhan. Hasil analisa sampel airtanah mengindikasikan bahwa akuifer yang dangkal dapat dikategorikan sebagai air segar. Pada zona pengendapan laut, kadar klorid dan sulfat dalam air tanah cenderung tinggi dalam sampel air. Namun kandungan ini masih dalam kategori aman untuk dikonsumsi oleh manusia. Pada lokasi yang banyak penggunaan pupuk kimia, sampel airtanah memperlihatkan kandungan nitrat relative tinggi, yang melebihi batas aman untuk dikonsumsi oleh manusia (>45 mg/L). Kadar K, Ca, Mg dan Na memiliki hubungan yang positif dengan kandungan klorid pada aquifer yang dalam, ini mengindikasikan bahwa ion-ion dalam air adalah berasal dari sumber air asin yang sama. Hubungan antara rasio Cl/HCO_3 dan chloride juga menunjukkan bahwa airtanah yang segar and air laut bercampur di dalam aquifer, dan sampel air dengan rasio yang rendah bisa dikategorikan air segar. Untuk aquifer yang dangkal, kebanyakan ion menunjukkan korelasi yang tidak linier dengan klorid yang mengindikasikan bahwa ion-ion tersebut berasal dari sumber yang berbeda..

***Kata kunci**: akuifer, kontaminasi, airtanah, hidrogeokimia, karakter fisika.*

INTRODUCTION

Water is most important natural resources for every nation in the world. The fresh (uncontaminated) water demand is increased as increasing of population. One of the sources of freshwater can be obtained from groundwater (Bethany et al, 2013). It provides daily usage to urban and rural communities, supports irrigation and industry, sustains the flow of streams and rivers, and maintains riparian and wetland ecosystems. The importance of groundwater for the existence of human society cannot be overemphasized (Islami et al, 2012).

The study area discussed in this paper covers the coastal area from Bachok, Tawang, Sabak, Pengkalan Chepa, and the surrounding area to the landward, North Kelantan. It covers an area with a width of approximately 7 km from the beach line elevated less than 10 m above mean sea level (Figure 1). The quality of local groundwater depends on the natural condition of the subsurface and the human activities or land uses of an area (Islami 2010[a]; Nusantara et al, 2014; Lisnawati et al, 2014). The land use in the south-eastern area is mainly for paddy planting. In Bachok, season crops planting, such as tobacco, corn, chili, and other vegetable plants, is the dominant agricultural activity. In the Pengkalan Chepa and Sabak areas, the dominant agricultural activity is the production of coconuts. The use of chemical fertilizers to enhance agricultural production is less than in the area where the palm oil plantations are predominant. However, the impact of the fertilizer use on the groundwater must be considered.

In the North Kelantan, groundwater is mainly water resources used for daily activities, that is supplied by the domestic water company (Air Kelantan Sdn Bhd). In order to meet the domestic demand, pumping activities are more intensive in certain areas including in pumping well stations. On the other hand, some rural communities use groundwater obtained from shallow aquifers for drinking water and other domestic usages. They develop conventional wells that are less than 10 m deep. Since this area is near the coastline, it must contain seawater intrusion, which can result from high water extraction rates or the existence of ancient brackish water that has been trapped in the subsurface for a long period of time. In this paper, the study is discussing on exploring the groundwater characteristic and its associated problem throughout the whole coastal area. Emphasis will be placed on identifying groundwater pollutants, including potential nitrate contamination and salt/brackish water in the aquifer.

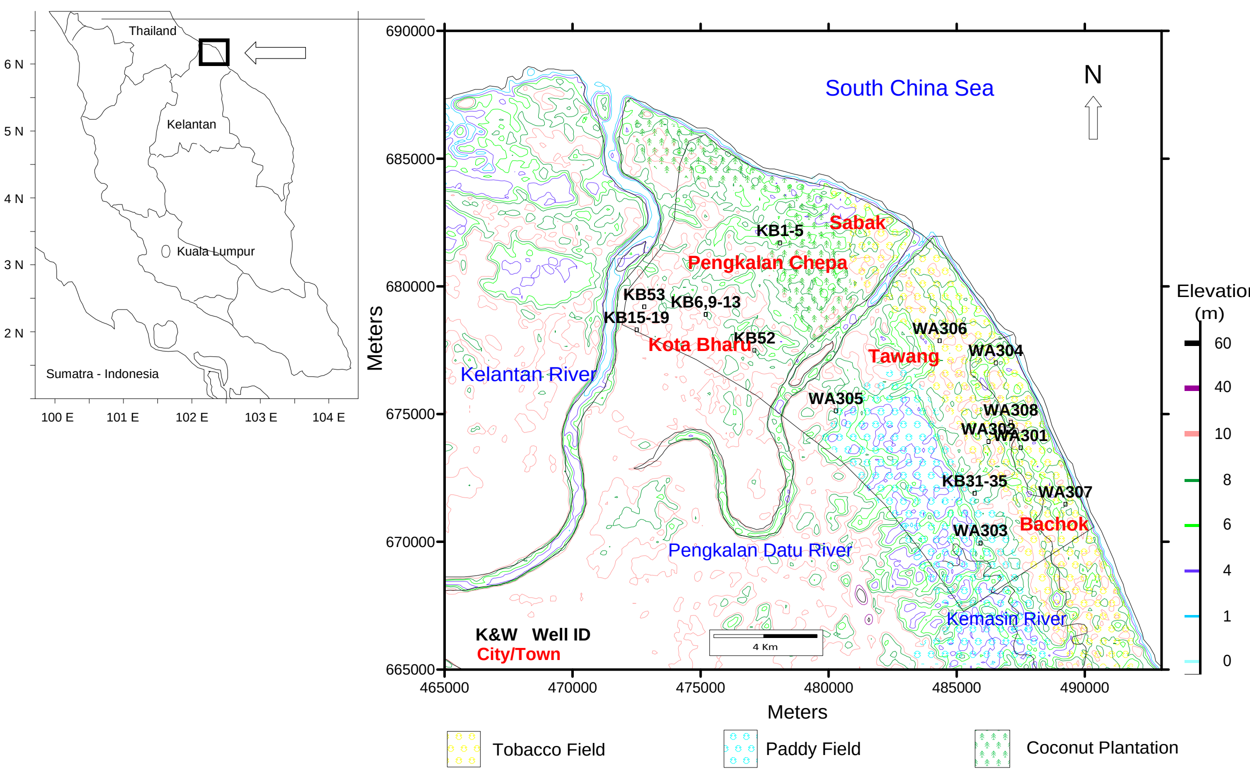

Figure 1. The map showing the location of wells, contour of topography (line with different color), river (colored blue word), town (colored red word) and the land uses (Modified after Mineral Geoscience Malaysia).

EXPERIMENTAL METHOD

Groundwater sample were collected from the existing wells during August 2013. In-situ physical water measurement and hydrogeochemical technique were used to study the groundwater problem in this area. The water pollution within the shallow aquifer including nitrate pollutant is one of the targets. This is because the nitrate can potentially contaminate the shallow aquifer as reported by Islami (Islami 2010[a]; Islami et al, 2012). Additionally, the first (shallow) aquifer from dug well is the main water resource for rural domestic especially in Bachok and Tawang area. Other water resources are obtained from a water company (Air Kelantan Sdn Bhd) that extracts groundwater from deeper aquifers (second and third aquifers).

Physical and chemical data obtained from this study (primary data), together with the data obtained from Jabatan Mineral dan Geosains Malaysia (secondary data), and were used in the interpretation. The groundwater samples were obtained at various depths from several wells. In the pumping well stations, the water samples were collected from the deepest aquifer (131 m depth) to the shallower aquifer (14 m depth). While, the water samples were collected from dug wells or piezometers is with depth of less than 7 m.

In-situ physical parameters such as well depth, water level, total dissolved solid, pH, conductivity, salinity and temperature in the existing wells were measured. Water samples of 500 mL were kept in plastic bottles and maintained at a temperature of 4 ^{o}C. This was done for determining their major ion contents analysis with IC available in the Hydrogeology Lab. The IC equipment was used to separate ions and polar molecules based on their affinity to the ion exchanger. A sample of groundwater was introduced with an autosampler, into a sample loop of known volume. A buffered aqueous solution known as the mobile phase carried the sample from the loop onto a column that contains some form of stationary phase material. After the a few minutes the negative charged ion contain of groundwater sample were produced. Whilst the ICP equipment was used to obtain the chemical contain of the groundwater sample especially for the positive charged of the chemical element. The groundwater sample was introduced to the ICP trough the nebulizer. It converts the groundwater sample into an aerosol, and that aerosol can then be swept into the plasma to create the ions. Physical information about water samples were retrieved directly from existing wells or piezometers whereas the physical information about these well, like well location, well depth, depth to water were obtained from the well owner. The physical and chemical data then was presented and analyzed using bivariate and piper diagram.

RESULTS AND DISCUSSION

The location of groundwater samples and the land use of the study area can be found in Figure 1. The groundwater samples are collected from shallow aquifer (wells starting with WA3) to deeper aquifer (wells starting with KB). The results of physical and chemical analysis of the groundwater samples are given in Table 1. The primary data which were collected in the field during the research is presented without underline and the secondary data collected from the Jabatan Mineral dan Geosains Malaysia are presented with underline.

In Table 1, the water sample obtained from the shallow aquifer of less than 7m deep has been grouped with the starting ID of WA, and the rest is water sample from deeper aquifer. Depth to water is relatively shallow (less than 2 m) in the shallow aquifer. While in the deeper aquifer, depth to water has an increasing trend with depth.

Total dissolved solid (TDS) is relatively low in the shallow aquifer although all the shallow aquifer relatively closer to the sea. In the deeper aquifer, TDS content is suddenly increased despite the well location is relatively far from the beach line. This condition indicates that materials in sea water have been intruding the deeper aquifer. This interpretation is also supported by salinity and conductivity data of the water sample that show relatively higher value.

Seventeen percent of the hydrogen ion concentrations (pH) in groundwater samples are slightly acidic and twenty nine percent are slightly alkaline. They are generally good for drinking and some other domestic uses.

Magnesium ion's (Mg^{2+}) concentration is generally low. The presence of magnesium ion in the shallow groundwater aquifer especially in the area of well named with WA3 (no 1-8 in Table 1) could be explained by the present of magnesium in carbonate powder (neutralising agent) distributed by the farmer before cultivation. Other possibilities of magnesium source are due to fertilizing activities especially by using chemical fertilizer containing of MgO. However, the magnesium content in the groundwater is generally safe for human use (Anonymous 1980; Anonymous 1984). At the Pengkalan Chepa pumping well station (KB1-5), magnesium content in the shallowest well (KB5, 24.5 m) and deepest well (KB1, 100 m) is 31 mg/L and 4.3 mg/L, respectively. In this location, the trend of magnesium concentration is decreasing with depth. The magnesium concentration in groundwater from other pumping well station (KB6-14), also show the same trend as KB1-5. However in the shallowest wells (KB11, KB12 and KB13), the magnesium concentration are still higher than the other deeper wells.

There are generally high sodium (Na) and potassium (K) concentration in the groundwater samples especially in the aquifer with depth of 20 to 35 m. This is due to the groundwater being contaminated by brackish water trapped in the aquifer (Samsudin et al, 2008). In the shallow aquifer, occurrence of sodium may be due to the natural system (i.e. rainwater) (Leboeuf 2004; Kouzana et al, 2008; Kim et al, 2013).

In the shallow aquifer (starting with well WA3), the chloride concentration is generally low (< 10 mg/L).

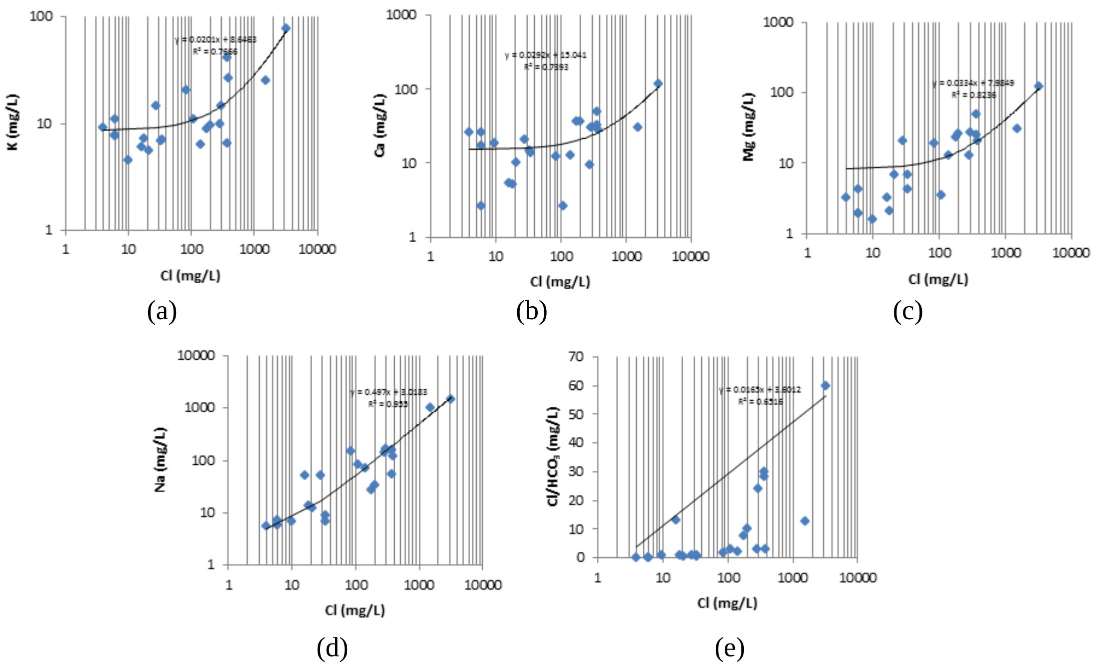

Figure 2. Bivariate plots of chemical constituents in groundwater for deeper aquifer. (a) K and Cl, (b) Ca and Cl, (c) Mg and Cl, (d) Na and Cl, and (e) $ClHCO_3$ and Cl.

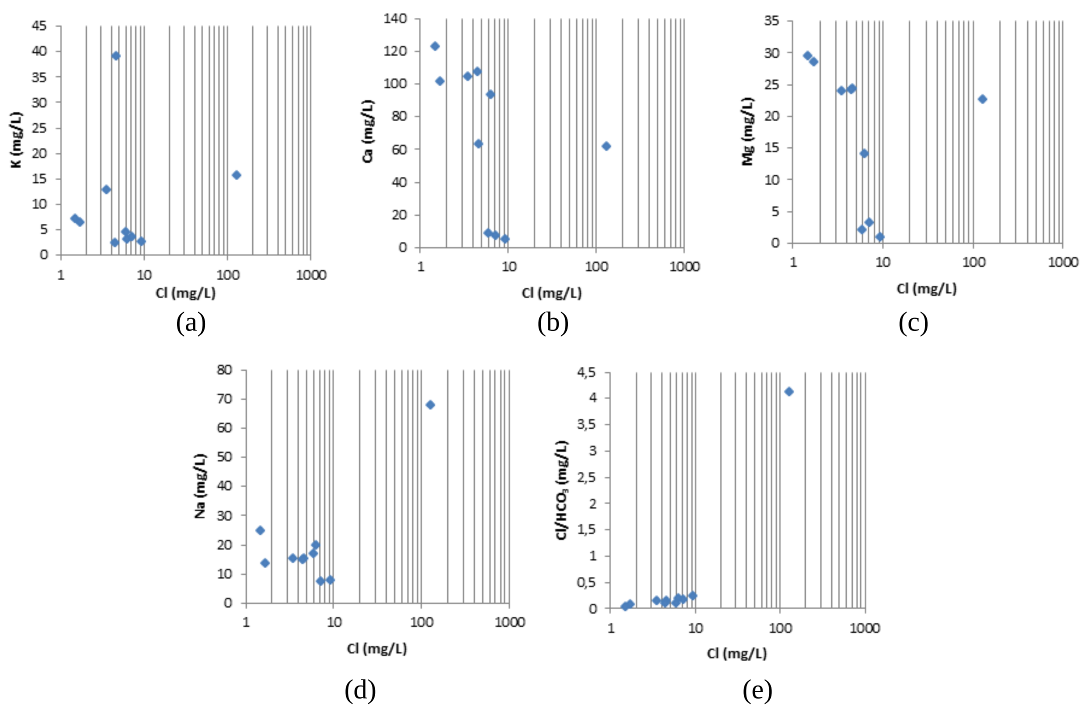

Figure 3. Bivariate plots of chemical constituents in groundwater for shallow aquifer. (a) K and Cl, (b) Ca and Cl, (c) Mg and Cl, (d) Na and Cl, and (e) $ClHCO_3$ and Cl.

Table 1. Water chemistry results. The non-underlined sample is the primary field data and the underline sample is the secondary data derived from Jabatan Mineral dan Geosains Malaysia

No	Sample ID	Location X	Location Y	Well Depth (m)	Ground Level (m)	Depth to Water (m)	Wtr.L(MSL) (m)	TDS (mg/L)	Cond. (mS/cm)	Salinity (0/00)	Temp (C)	pH
1	WA301	487496	673681	3.82	5	2.22	2.78	344	706	0.3	29.5	7.5
2	WA302	486240	673924	3.56	5	2.38	2.62	349	717	0.3	29.5	7.3
3	WA303	485508	675518	3.18	4	2.38	1.62	289	595	0.3	29.8	7.8
4	WA304	486528	677007	4.12	5	2.33	2.67	421	861	0.4	29.7	7.2
5	WA306	484332	677870	6.12	8	1.5	6.5	348	715	0.3	28.9	7.7
6	WA305	484809	678385	3.48	8	0.5	7.5	297	611	0.3	28.3	7.9
7	WA307	489246	671471	5.3	5	1.1	3.9	572	984	0.3	28.3	7.7
8	WA308	487115	674683	<6	10	2.3	7.7	427	863	0.1	28.1	7.6
9	KB1	478100	681700	100	5.93	5.03	0.9	100	185	None	None	7.2
10	KB2	478100	681700	87	5.93	5	0.93	106	197	None	None	7.1
11	KB3	478100	681700	68.5	5.87	4.99	0.88	380	624	None	None	7.1
12	KB4	478100	681700	59.5	5.85	4.95	0.9	426	698	None	None	6.7
13	KB5	478100	681700	24.5	5.79	4.42	1.37	2594	5100	None	None	7.1
14	KB6	475200	678900	129	4.48	8.71	-4.23	72	89	None	None	7.3
15	KB9	475200	678900	55.5	4.49	7.73	-3.24	126	194	None	None	8
16	KB10	475200	678900	31.5	4.65	6.25	-1.6	512	1048	None	None	7.4
17	KB11	475200	678900	32	4.5	6.11	-1.61	278	570	None	None	8.1
18	KB12	475200	678900	32	4.49	6.08	-1.59	516	1069	None	None	8.2
19	KB13	475200	678900	31.5	4.41	6.16	-1.75	512	1188	None	None	6.4
20	KB15	472500	678300	126.5	6.57	5.49	1.08	230	85	None	None	6.9
21	KB16	472500	678300	110	6.58	5.43	1.15	130	177	None	None	7.3
22	KB18	472500	678300	65	6.55	5.56	0.99	110	170	None	None	7.1
23	KB19	472500	678300	28.5	6.47	5.37	1.1	140	190	None	None	7.3
24	KB22	486500	664700	50.4	3.61	1.4	2.21	50.4	106.6	0	30.6	6.1
25	KB23	486500	664700	32.4	3.58	2.07	1.51	95.6	200	0.1	30.6	6.1
26	KB24	486500	664700	9.4	3.61	1.67	1.94	26.5	56	0	30.6	6.1
27	KB52	477100	677500	21	4.91	None	None	96	151	None	None	7
28	KB53	472800	679200	14	2.52	6.24	-3.72	96	175	None	None	8
29	KB31	485700	671900	131.4	3.39	2.84	0.55	498	1014	0.5	28.7	6.8
30	KB32	485700	671900	101.2	3.6	2.8	0.8	167.6	384	0.2	28.7	7.5
31	KB33	485700	671900	83.4	3.33	2.85	0.48	943	1883	1	28.9	7.2
32	KB34	485700	671900	40.4	3.34	3.1	0.24	3630	6850	3.7	28.8	6.5
33	KB35	485700	671900	29.2	3.39	2.85	0.54	314	645	0.3	28.8	6.9

Table 1. (Continued)

No	Sample ID	Chloride mg/L	Nitrate mg/L	Sulfate mg/L	Fluoride mg/L	K mg/L	Ca mg/L	Mg mg/L	Na mg/L	Al mg/L	Fe mg/L	CO_3^{2-} mg/L	HCO_3^- mg/L
1	WA301	3.5	0	35.2	0	12.8	104.7	23.9	15.4	0	1.8	2.5	24.4
2	WA302	1.7	0	16.4	0	6.5	101.2	28.6	13.6	0	3.5	2.5	25.1
3	WA303	6.3	0	7	0	3.1	93.1	14	19.9	0	0.1	2.5	33.8
4	WA304	1.5	0.3	52	0	7.1	123	29.6	24.8	0	2	2.5	38.6
5	WA306	4.5	0	24.5	0	2.3	107	24.1	15	0.2	0.9	5	42
6	WA305	4.6	1.4	15.4	0	39	63.1	24.3	15.3	0	0	5.9	30.2
7	WA307	130.4	29.2	83.8	0.1	15.7	61.8	22.7	68	0	0	2.1	31.7
8	WA308	7.2	12.5	0	0	3.5	7.2	3.2	7.6	0.1	0.3	2	39.5
9	KB1	34.0	1.4	<5	<0.5	7.1	14.0	4.3	9.1	0.0	10.0	<1	40.0
10	KB2	33.0	1.1	<5	<0.5	6.8	15.0	6.9	6.7	0.0	13.0	<1	50.0
11	KB3	177.0	2.5	<5	<0.5	8.8	36.0	23.0	27.0	0.0	18.0	<1	23.0
12	KB4	200.0	3.7	<5	<0.5	9.7	37.0	26.0	33.0	0.0	18.0	<1	20.0
13	KB5	1527.0	13.0	<5	<0.5	25.0	30.0	31.0	1028.0	0.0	20.0	<1	121.0
14	KB6	6.0	2.8	<5	<0.5	7.6	2.6	1.9	7.3	0.0	5.8	<1	32.0
15	KB9	21.0	2.8	<5	<0.5	5.5	10.0	6.9	12.0	0.0	9.9	<1	72.0
16	KB10	281.0	1.9	<5	<0.5	10.0	9.5	13.0	142.0	0.0	10.0	<1	91.0
17	KB11	140.0	1.6	<5	<0.5	6.4	13.0	13.0	70.0	0.0	9.1	<1	69.0
18	KB12	298.0	2.9	<5	<0.5	14.7	30.4	27.4	164.8	0.0	17.4	0.0	12.3
19	KB13	368.0	0.6	<5	<0.5	6.5	49.0	49.0	55.0	0.0	20.0	<1	13.0
20	KB15	110.0	3.4	<5	<0.5	11.0	2.6	0.5	85.0	0.0	3.8	<1	36.0
21	KB16	4.0	2.4	<5	<0.5	9.2	26.0	3.2	5.5	0.0	1.6	<1	99.0
22	KB18	6.0	3.2	<5	<0.5	11.0	17.0	4.3	5.9	0.0	7.4	<1	82.0
23	KB19	6.0	1.3	5.0	<0.5	7.8	26.0	1.9	5.9	0.0	2.3	<1	96.0
24	KB22	9.8	0.6	1.3	0.0	4.5	18.3	1.6	7.0	0.0	0.5	0.0	11.4
25	KB23	16.2	0.0	0.0	0.2	6.1	5.4	3.2	52.5	0.0	3.6	3.4	0.0
26	KB24	9.4	0.1	3.2	0.1	2.7	5.3	1.0	7.8	0.0	0.8	3.5	0.0
27	KB52	18.0	7.0	22.0	<0.5	7.2	5.2	2.1	14.0	0.0	0.2	<1	18.0
28	KB53	6.0	4.3	9.0	<0.5	4.5	8.6	2.1	17.0	0.0	0.4	<1	55.0
29	KB31	369.7	0.1	0.3	0.2	42.0	33.1	25.3	157.9	0.0	63.9	0.0	0.0
30	KB32	28.1	0.0	0.1	0.3	14.6	21.0	21.0	50.8	0.0	0.3	7.7	30.7
31	KB33	382.3	0.4	0.7	0.8	26.9	27.7	20.5	119.8	0.0	34.8	31.1	128.7
32	KB34	3206.6	0.0	0.3	0.3	77.7	119.0	123.1	0.0	0.0	6.0	28.6	53.8
33	KB35	83.9	0.1	0.0	0.8	20.3	12.3	19.2	151.3	0.0	0.2	11.4	44.2

The influence of marine shale may have been a contributory factor of the chloride content in the northern part of the study area. The highest chloride content (130 mg/L) can be found in well WA307 where it is located around 200 m from the beach line. The chloride concentration in the water samples are within the accepted limits for human consumption.

In the deeper aquifer (pumping well station), relatively higher chloride concentration of more than 1000 mg/L was observed in all wells with depths ranging from 25 m to 40 m. However, at Tanjung Mas pumping well station (KB12, KB13), chloride concentration ranges from 298 to 368 mg/L. The relatively lower chloride concentration at the Tanjung Mas pumping wells station is due to these wells are located relatively far from the beach line (approximately 7 km from the sea) and also although it’s location in between two revers, however these wells are quite far from rivers if compare than other wells.

In general, most ions are positively correlated with chloride ions. K, Ca, Mg and Na show a strong correlation with chloride in the deeper aquifer (Figure 2), indicating that such ions are derived from the same source of saline waters. The Bivariate plots of chemical constituents in groundwater for deeper aquifer are presented in Log scale due to relatively higher gap among the values. The relationship between Cl/HCO_3 ratios and chloride also shows mixing of fresh groundwater and seawater, and the samples with lower ratios can be characterized as fresh waters (Kim et al, 2013; Hamed et al, 2013; Nosetto et al, 2013).

Figure 3 shows the correlation between K, Ca, Mg and Na with chloride content for shallow aquifer. The shallow aquifer is contradictory to the deeper aquifer. In the shallow aquifer, most ions exhibit a bad correlation. It indicates that such ions are derived from a different source. This is due to the presence of well WA307 (Figure 3) that is very near to the beach. It is possible that the water sample in this well indicates the occurrence of brackish water. High chloride concentration in the WA307 well was because of its distance of around 500 m from the beach line and well depth below -30 cm relative to the mean sea level.

In the shallow wells (starting with WA3), relatively higher nitrate concentration is observed at wells A307 (29.2 mg/L) and A308 (12.5 mg/L). While, in the other shallow wells, nitrate concentration vary from 0 to 1.4 mg/L. Nitrate concentration in groundwater does not show any specific correlation with depth. The potential source of nitrate in the area of shallow wells may include animal excrements and agriculture activities (chemical fertilizers usage). In the area around the well WA307 and WA308, after the tobacco season is ended, the farmers plant corn and other vegetable planting. Islami (2010[b]) also reported that shallow groundwater was vulnerable contaminated by nitrate due to farming activities.

In the deeper wells (starting with KB), the highest nitrate concentration of 13 mg/L is found in the shallowest well (KB5, 24.5 m depth) at Pengkalan Chepa well station. This may be due to the accumulation of nitrates from the surface to the aquifer through the semi confined material. Whilst in the other wells, nitrate concentration is ranging from 0 to 4 mg/L. Generally, the nitrate concentration tends to be higher during intensive agriculture activity. However, it is still within accepted limit for human consumption (less than 45 mg/L). Figure 4 shows the piper diagram of the groundwater sample. Most shallow groundwater is dominated by Ca-HCO_3 facies that indicates fresh water with low TDS <1000 mg/L. Other facies in shallow groundwater are influenced by antropogenic source. Deep groundwater shows variable facies from Ca-HCO_3, mix facies and Na-CI. Ca-HCO_3 facies which is fresh water in deep GW is shown by well inland area (Figure 1). Towards coastal area, the facies change to Na-CI facies indicates possible mixing with sea water or entrapped sea water in sediment during late Holocene (Samsudin et al, 2008). Therefore, deep groundwater also shows brackish water in selected area. The evolution of groundwater in this coastal area is influenced by weathering, dissolution, ion exchange and precipitation process (Samsudin et al, 2008).

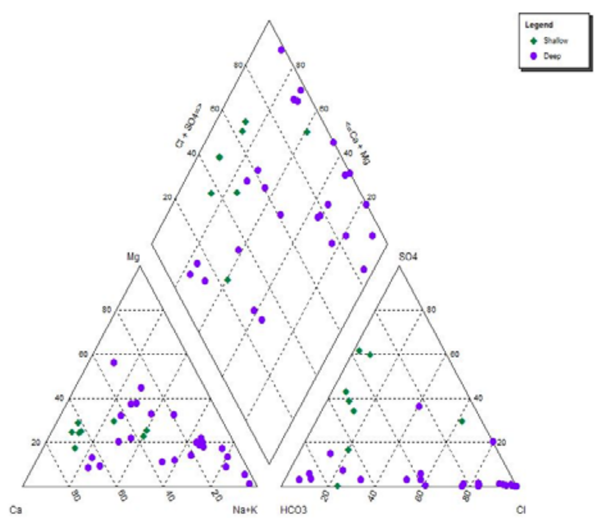

Figure 4. Piper diagram of the groundwater samples.

Generally, the groundwater from shallow aquifer (less than 7 m depth) in this study area, are safe for human consumption due to the low chloride content and other constituents from sea water. However, the deeper aquifer is contaminated by seawater for the reason that the higher pumping rate of groundwater for community use, and also due to the ancient sea water that trapped along geologic time. The chemical content of ground water is highly influenced by the seawater and finally causes the different facies groundwater type produced.

CONCLUSION

Analysis on water physical and chemical data has been demonstrated successfully in this paper. The study is to explore the groundwater characteristics and their associated problem. Interpretation of the data indicates that the groundwater in the shallow aquifer is fresh water. In deeper aquifer, the ions in groundwater samples are derived from the same source of saline waters. The relationship between Cl/HCO_3 ratios and chloride content in water samples show that fresh groundwater and seawater are mixed, and the samples with lower ratios can be characterized as fresh waters. For the shallow aquifer most ions exhibit a bad correlation to chloride indicating that such ions are derived from a different source. The facies of groundwater is more influenced by the present of sea water in the groundwater sample. The groundwater derived from shallow aquifer is safe for human consumption, whilst the deep aquifer is not due to have been contaminated by intruded sea water.

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