

Hydrochemistry of groundwater at Sabahat region, Sabah

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Abstract: The rolling land of the Sabahat region is currently developed by FELDA agency into one of the major palm oil estates in Sabah. The estimated total water demand for both domestic and palm oil industry is about 5.90 Mld. From hydrologic evaluation of surface and ground water, the latter appears to be the main water resource available in this region.

Analyses of groundwater obtained from exploratory wells during pumping tests show that some of the groundwater, after proper treatment, are suitable for domestic and agricultural usage. Chemical analyses of groundwater samples show that there is a definite chemical contrast between groundwater from the northern and southern parts of the Sabahat region. The groundwater at the northern part of the region has proportionally higher concentrations of (Na + K) and (SO₄ + Cl), with proportionally lower concentrations of (Ca + Mg) compared to the groundwater present in the south. The groundwater between these two localities has intermediate composition probably derived from mixing of the groundwater from the northern and southern parts of the region. The groundwater in the north is probably connate water of marine origin and not a result of sea water incursion, whilst groundwater in the south is probably influenced by the presence of gypsum present in the Ganduman Formation.

INTRODUCTION

An area of about 17 km² in Sabahat peninsula in eastern Sabah, is currently being developed into a major oil palm estate by the FELDA agency. Water is required not only for irrigation purposes but also for estate settlers' consumption as well as for oil palm milling activities. The estimated total water requirement is about 5.90 Mld. Before the realization of the oil palm estate in this area, it was thought that the water requirement could be furnished from Sungai Togopi which is the main river flowing in this area. However after some hydrologic studies on Sungai Togopi which has a relatively low flow condition throughout the year, direct water abstraction from Sungai Togopi was deemed to be insufficient as it could only provide 0.34 Mld. Pump storage reservoir of Sungai Togopi water could possibly give a maximum yield of about 6 Mld. However this expected yield is unrealistic and probably unreliable since the Sabahat peninsula experiences drought frequency of 1 in 30 years. In addition, Sungai Togopi water would probably be subjected to pollution especially from pesticides and agroicides that are being used in the oil palm estates, making its water unsafe for human consumption. The other best option is to explore groundwater potential in this area. Groundwater is preferred since it would not be exposed to the vagaries of nature.

GEOLOGY

Geologic studies show that the area is dominated by sedimentary rocks collectively known as the Dent Group (Sanudin and Tan, 1986; Sanudin, 1989). The Dent Group unconformably overlies a sequence of older sedimentary rocks collectively known as the Segama Group which outcrop mainly on the western side on the peninsula. Based on field evidence, stratigraphic relationship and fossil record, the age of the Segama Group is Middle Miocene (Tf1 to Tf3), whilst that of the Dent Group is Upper Miocene to Pleitocene (Tg to Q). The geology of the area is shown in Figure 1.

As the Segama Group occurs outside the area of interest, only the geology of the Dent Group is discussed. The Dent Group as a whole consists of a thick sequence of mainly marine sediments with subordinate limestone. The Group comprises of three sedimentary formations, viz.

- (a) Sabahat Formation
- (b) Ganduman Formation
- (c) Togopi Formation

The Sabahat Formation being the oldest formation consists mainly of mudstone with subordinate sandstone, marl and shale, with occasional calcareous sandstone and conglomerate interbeds. Outcrops of this formation occur mainly on the western side of the study area. The formation which is estimated to be over 2,300 m thick, was

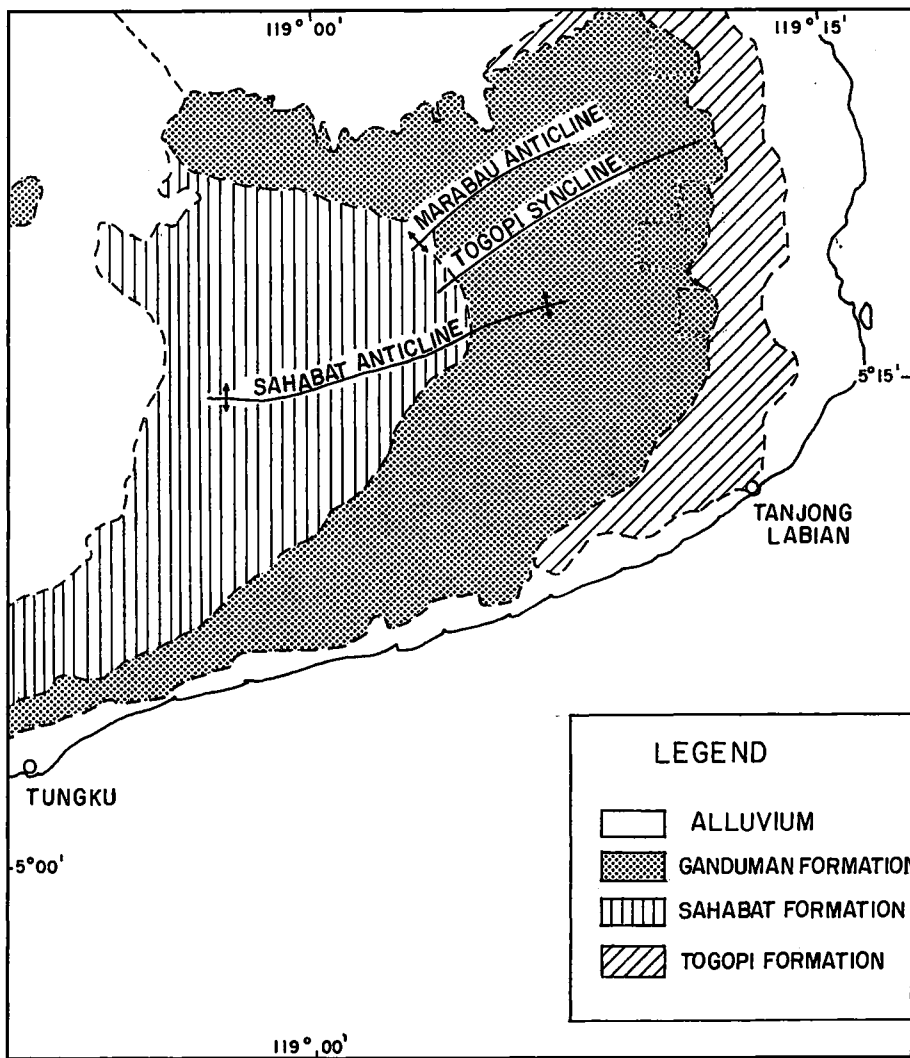


Figure 1. General geology of Sabahat area, Sabah.

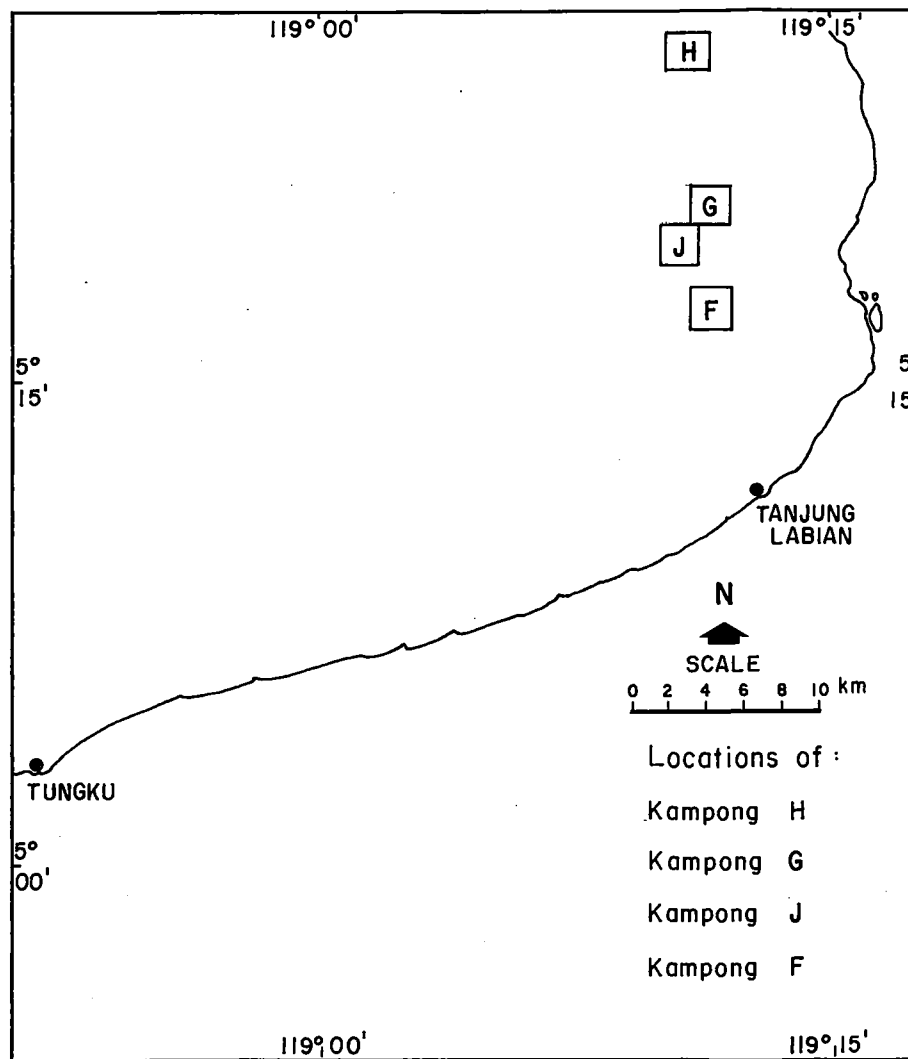


Figure 2. Locations of wells at various kampongs in Sabahat area.

deposited during Neogene time in sublittoral and neritic zones (Haile and Wong, 1965).

The Ganduman Formation which conformably overlies the Sabahat Formation, comprises of successions of loosely cemented porous sandstone beds occasionally interrupted by a few carbonaceous claystone interbeds. This formation outcrops in the central zone of the study area. The total thickness of this formation is estimated to be about 1,100 m (Haile and Wong, 1965). The Ganduman sandstone is medium to coarse grained with bed thickness varying from a few centimeters to more than 10 m. The thickness of the claystone interbeds varies from 2 to 5 cm. Some coarse crystals of gypsum, plant remains and lignite are present as fossils in this formation.

The Togopi Formation being the youngest formation consists mainly of cemented limestone, calcareous sandstone, clay and marl. This formation occurs mainly on the eastern side of the study area. Well preserved foraminifera, molluscs and corals are present in this formation.

Of the three formations mentioned above, only the Ganduman sandstone owing to its porosity, has

the characteristics of an aquifer. The other formations are generally dominated by rocks that are either impermeable or slightly permeable, making them unfavourable to groundwater infiltration, transmission and storage.

HYDROCHEMISTRY OF SABAHAHAT GROUNDWATER

Exploratory and observation wells were placed in the vicinity of Kampong F, Kampong G, Kampong H and Kampong J (Fig. 2). Kampong F occurs in the south, whilst Kampong H in the north, and Kampongs G and J occur in between Kampongs F and H. Continuous and step pumping tests as well as recovery tests had been conducted at each well site to determine the various hydrological parameters, viz. transmissibility, permeability, storage and well yield. Several water samples were also taken during these tests, and these samples were subsequently analysed for various constituents. The average analytical data of the groundwater samples at different well sites are shown in Table 1.

Table 1. Average analytical data of Sabahat groundwater at Kampong F, G, H and J (Concentrations in mg/l).

	Kampong			
	F	G	H	J
Na	20.62	209.43	448.96	452.00
K	1.72	3.88	7.63	7.53
Mg	29.50	23.80	32.10	34.00
Ca	72.63	12.88	8.44	6.70
Fe total	5.87	0.40	8.91	5.66
Mn	0.22	0.02	0.19	0.11
Si	56.86	20.64	36.54	24.59
Cu	0.01	0.01	0.02	0.02
Pb	ND	ND	ND	ND
As	ND	ND	ND	ND
Cl	15.09	17.04	348.29	26.87
SO ₄	178.00	ND	ND	ND
CO ₃	2.79	9.40	10.23	12.28
PO ₄	1.35	4.44	5.85	3.41
N (as ammonical nitrogen)	0.70	2.58	5.23	3.31
NO ₂	0.03	0.23	0.19	0.01
NO ₃	2.33	0.50	1.70	ND
CN	ND	ND	ND	ND
F	0.49	0.75	0.69	0.26
Total dissolved solids	674.50	826.60	1839.00	774.00
Total hardness (as CaCO ₃)	351.50	11.20	28.70	14.00
Free O ₂	0.08	0.15	0.21	0.22
Free CO ₂	0.12	12.00	27.67	14.80
pH	7.10	7.90	7.80	7.90
SAR	2.88	48.93	99.77	100.22

ND denotes not detected.

SAR denotes sodium absorption ratio.

The groundwater throughout the Sabahat region is generally alkaline with pH values varying from 7.10 to 7.90. The water generally contain high amount of total dissolved solids suggesting that there could be considerable amounts of cations and anions present in them. In the northern part of the study area (i.e. in the vicinity of Kampong H), the average total dissolved solid content in groundwater is about 1,839.00 mg/l, whilst that in groundwater present elsewhere (viz. in the vicinity of Kampongs F, G and J) are relatively lower with values varying from 674.50 to 826.60 mg/l.

The groundwater in the vicinity of Kampong F contains relatively high calcium and magnesium content whilst groundwater elsewhere is characterized by relatively high alkaline earth (Na + K) content. As shown in Table 1, the average Na content in the groundwater in the vicinity of Kampong F is about 20.62 mg/l, whilst that in the groundwater in the vicinity of other kampongs (Kampong G, H and J) are several times higher with values ranging from 209.43 to 452.00 mg/l. The K constituent in groundwater is not as significantly high as its Na content, with values ranging from 1.72 to 7.63 mg/l. The high Na content in the groundwater in the vicinity of Kampongs G, H and J correspond with their high sodium adsorption ratio (SAR) which varies from 48.93 to 100.22. The SAR value for groundwater in the vicinity of Kampong F is low with a value of 2.88.

The calcium content in the groundwater shows a contrasting pattern compared to its alkaline earth (Na + K) content. The Ca content in groundwater in the vicinity of Kampong F is relatively high with an average value of about 72.63 mg/l, whilst that in the vicinity of other kampongs are several times lower with values ranging from 6.70 to 12.88 mg/l. Owing to the presence of high calcium content, the groundwater in the vicinity of Kampong F has a Ca hardness of 351.50 mg/l, whilst groundwater elsewhere has relatively lower hardness values ranging from 11.20 to 28.70 mg/l.

The concentrations of other cations in the groundwater throughout the Sabahat region (viz. Mg, Fe, Mn, Si and Cu) are relatively low without any significant geochemical contrast at different well sites. Among the cations mentioned, only Mg and Si constituents are relatively high; the Mg content in the groundwater varies from 23.80 to 34.00 mg/l, whilst the Si content from 20.64 to 56.86 mg/l. The Fe values range from 0.40 to 8.91 mg/l, whilst the Mn and Cu values are below 0.22 mg/l.

Regarding the anion composition, the groundwater in the vicinity of Kampong F has chemical characteristics different from groundwater present in the vicinity of other kampongs. It has relatively high sulphate content with an average

value of about 178.00 mg/l, whilst the groundwater elsewhere (Kampongs G, H and J) has negligible SO_4 content. The chloride content in most of the groundwater in the Sabahat region with an exception of groundwater in the vicinity of Kampong H, is relatively low with values varying from 15.09 to 26.87 mg/l. Groundwater in the vicinity of Kampong H contains an exceptionally high Cl content with an average value of about 348.9 mg/l which is almost comparable to its high Na content. Although the carbonate and phosphate content in groundwater are generally low, with values varying from 2.79 to 10.28 mg/l and from 1.35 to 5.85 mg/l respectively, the groundwater in the vicinity of Kampongs G, H and J contain slightly higher proportions of CO_3 and PO_4 compared to groundwater in the vicinity of Kampong F. Incidentally the amount of CO_3 present in the groundwater corresponds with the amount of free CO_2 present in the water. The groundwater in the vicinity of Kampong F contains 0.12 mg/l of free CO_2 , whilst groundwater elsewhere has relatively higher free CO_2 content with values varying from 12.00 to 27.67 mg/l.

NH_3 , NO_x , F and free O_2 content in the groundwater are generally low throughout the Sabahat region, and they do not show any significant hydrochemical contrast in groundwater from different well sites. Their values are below 6 mg/l.

DISCUSSION

The relative proportions of major cations and anions present in groundwater at each well site can be shown in bar diagrams (Fig. 3). The latter show that there are at least three distinct types of groundwater each with its own chemical characteristics. The groundwater in the southern part of the study area (i.e. in the vicinity of Kampong F), is characterized by proportionally higher Ca, Mg and SO_4 content compared to its Na-K, Cl and CO_3 - HCO_3 components. In the northern part (i.e. in the vicinity of Kampong H), the groundwater has relatively high Na-K and Cl content with relatively low Ca, Mg and CO_3 - HCO_3 components. Groundwater in between these two areas (i.e. in the vicinity of Kampong G and Kampong J) contain proportionally higher Na-K content and lower Ca, Mg, Cl and CO_3 - HCO_3 components with respect to the composition of groundwater present in the south. As stated earlier, the sulphate content is only present in groundwater in the south.

The chemical characteristics of groundwater at each well site can be further discerned using trilinear plot (Piper, 1953) as shown in Figure 4. The trilinear plot also show that there are three distinct types of groundwater, each with differing

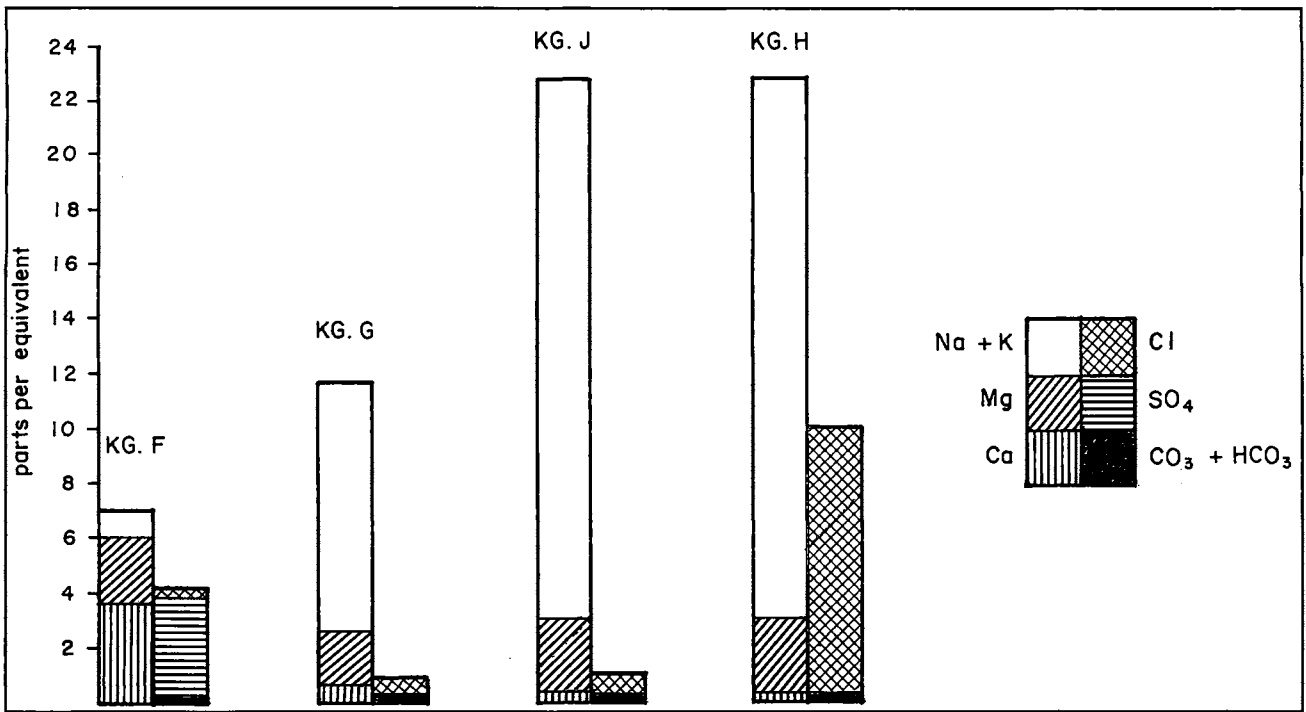


Figure 3. Compositional bar diagrams for Sabahat groundwater.

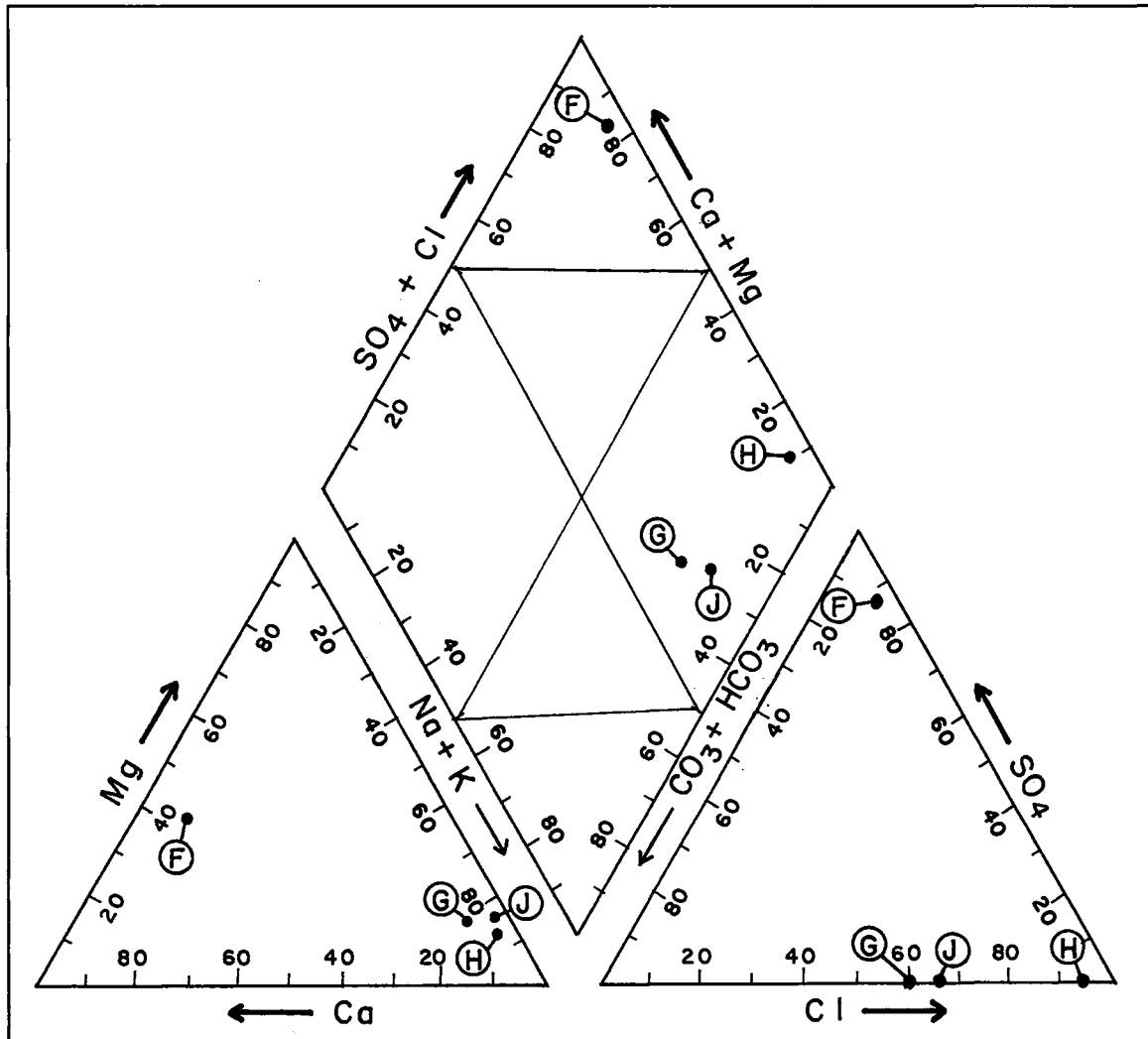


Figure 4. Trilinear compositional plot for Sabahat groundwater.

chemical compositions as mentioned above. The chemical compositional plot for groundwater in the southern part of the study area (i.e. in the vicinity of Kampong F), occurs isolated away from compositional plots for other groundwater present elsewhere. This groundwater is characterized by relatively high amount of Ca, Mg and SO₄ content. Closer examination of the trilinear plot, especially the Cl-SO₄-HCO₃-CO₃ sector and the quadrilateral sector, shows that the compositional plot for groundwater present in the northern part of the study area (i.e. in the vicinity of Kampong H) is plotted slightly away from compositional plots for groundwater present in the vicinity of Kampongs G and J. The compositional plots for groundwater from the latter two kampongs occur quite near to one another, suggesting that the water there have almost similar compositions. Groundwater present in the north contains relatively high amount of Na-K and Cl, compared to the groundwater in the vicinity of Kampongs G and J. Groundwater in the vicinity of Kampongs G, H and J, unlike that in the vicinity of Kampong F, has relatively low Ca and Mg as well as negligible SO₄ content.

From the bar diagram and the trilinear plot, it can be suggested that the intermediate composition of groundwater present in the vicinity of Kampongs G and J had probably resulted from mixing of groundwater present in the northern and in the southern part of the study area. Mixing of groundwater should however be verified graphically using the trilinear plot or mathematically using the following formula:

$$E_m = \frac{E_a E_b (a_i + b_i)}{a_i E_a + b_i E_b} \quad (a)$$

$$V_a = \frac{b_i E_b}{a_i E_a + b_i E_b} \quad (b)$$

$$C_m = C_a V_a + C_b V_b \quad (c)$$

where E_a = concentration of water A, in epm
 E_b = concentration of water B, in epm
 E_m = concentration of mixture, in epm
 a_i = intercept between water A and mixture
 b_i = intercept between water B and mixture
 V_a = proportional concentration of a component in mixture and water A
 V_b = proportional concentration of a component in mixture and water B
 C_m = concentration of a component in mixture, in epm
 C_a = concentration of a component in water A, in epm
 C_b = concentration of a component in water B, in epm

Using either total concentration of major elements or Na-K components which are present ubiquitously in all the groundwater, the calculated data E_m , V_a and C_m are listed below. The calculated data though showing some discrepancies agree quite reasonably well with the laboratory data, confirming that groundwater in the vicinity of Kampongs G and J is a mixture of groundwater present in the northern and in the southern part of the study area.

	Calculated data	Laboratory data
E_m	18.21	11.81
V_a	0.72	0.78
C_m	9.29	9.21

From the quadrilateral sector in the trilinear plot, it can be further summarized that the groundwater in the Sabahat region generally has components of strong acids (viz. SO₄ and Cl) dominating over components of weak acids (viz. CO₃ and HCO₃). Alkaline earth components (viz. Ca and Mg) dominate alkali components (viz. Na and K) in groundwater present in the south, and vice versa in groundwater present elsewhere. In addition, the groundwater in the south which is characterized by relatively high Ca and SO₄ content, has high non-carbonate hardness values. The high Ca and SO₄ content could be derived from gypsum present in the Ganduman Formation. Groundwater present elsewhere except in the south, generally contain relatively high non-carbonate alkalies (viz. Na, K and Cl). The latter components could arise either from sea water incursion (Walton, 1970) or from connate water with high sodium and chloride content present in the northern part of the study area.

As all the wells were placed within the Ganduman Formation which is separated from the coastal alluvium by the impermeable Togopi Formation, present sea water incursion could not have occurred in the vicinity of Kampong H, even though the groundwater there contains excessively high amount of sodium and chloride. In addition, should sea water incursion had taken place, especially during pumping tests, the groundwater in the vicinity of Kampongs F, G and H should have high sodium and chloride content since the wells are aligned almost linearly in a north-south direction almost parallel to the coastline. Ruling out sea water incursion, the groundwater in the northern part of the study area (i.e. in the vicinity of Kampong H) is probably connate water of marine origin. Towards the south (i.e. in the vicinity of Kampong F), salty connate water is probably lacking due to possible discharge or migration of sodium

and chloride components towards the north. In addition the presence of gypsum crystals within the Ganduman Formation could have resulted high calcium and sulphate content in the groundwater in the south. Along this migration path the groundwater in the vicinity of Kampongs G and J assumed an intermediate composition reflecting mixing of groundwater occurring in the northern and in the southern part of the study area (i.e. between Kampongs F and H). With more wells to be installed at a later period, it should not be surprising that more pools of connate water containing high sodium and chloride content could be found in the Sabahat region.

The unusually high sodium content in groundwater in the vicinity of Kampong J, G and H may also suggest occurrence of active base exchange processes occurring between groundwater and soil-rock bodies. The high Na content together with low calcium and magnesium content in these groundwater have caused the water in having high sodium adsorption ratio values (SAR). The SAR values for groundwater in the vicinity of Kampongs J, G and H vary from 48.93 to 100.22. The SAR value for groundwater in south (i.e. in the vicinity of Kampong F) is relatively low with a value of 2.88. Water with SAR values exceeding 10 is generally not suitable for agricultural, palm oil milling plants, and human consumption purposes prior to any water treatment.

Beside base exchange processes, processes of sulphate reduction must have occurred in the groundwater present in the north (i.e. in the vicinity of Kampongs J, G and H), since the groundwater at these locations have negligible sulphate content. Sulphate reduction would generally cause the groundwater to be enriched in H_2S . Little or no sulphate reduction had occurred in groundwater present in the southern part of the study area (i.e. in the vicinity of Kampong F) since the groundwater there contain an average of 178.00 mg/l of sulphate. As mentioned earlier, high sulphate content in groundwater could have arise from coarse gypsum crystals present in the Ganduman Formation.

CONCLUSION

In the above discussion, it is obvious that hydrochemical investigations play an important role in any hydrologic study, particularly in determining the origin, composition, mixing of water from different sources, pattern of migration, quality and suitability of groundwater for irrigation, palm oil milling plants as well as human consumption. The conclusions that could be drawn from this study are as follow:

- (a) there are three types of groundwater each with its own distinct chemical composition present in the Sabahat region. The northern part of the study area contains marine connate groundwater which is characterized by relatively high Na and Cl content. The groundwater present in the southern part of the study area contains relatively high Ca and SO_4 content, both of which could have been derived from dissolution of gypsum crystals present in the Ganduman Formation. Mixing of these two types of groundwater have resulted in groundwater with intermediate compositions which occur in between the northern and the southern part of the study area mentioned earlier,
- (b) sea water incursion into the groundwater had not occurred even during heavy pumping tests since all the wells are located within the Ganduman Formation which is separated from the sea by the Togopi Formation and coastal alluvium. If sea water incursion had taken place, it would not have confined to groundwater present in the north since all the wells are installed linearly in a north-south direction almost parallel to the coast line,
- (c) the unusually high Na content in the connate groundwater present in the northern part of the study area, could have resulted from active base exchange processes occurring between groundwater and soil-rock bodies,
- (d) sulphate reduction processes probably occurred in groundwater in the northern part of the study area, since the groundwater there contains negligible amount of sulphate. Sulphate reduction usually result in the formation of H_2S in the water. The groundwater in the south contains relatively high amount of sulphate, suggesting little or no sulphate reduction occurring there,
- (e) though the groundwater throughout the region generally do not contain toxic elements, the groundwater in the south is more suitable for agricultural, oil milling plants and human consumption since it has relatively low SAR values, as compared to groundwater present in the northern part of the study area. Groundwater present in the vicinity of Kampongs H, G and J has to be treated or desalinated prior to any usage.

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