

Assessment of Selected Chemical and Microbial Parameters in Groundwater of Pulau Tiga, Sabah, Malaysia

(Taksiran Parameter Kimia dan Mikrob Terpilih Bagi Air Bawah Tanah di Pulau Tiga, Sabah, Malaysia)

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ABSTRACT

Ambient groundwater samples collected from five wells in Pulau Tiga have been studied for selected physico-chemical and biological parameters to understand general water quality of the island. This preliminary study on groundwater of Pulau Tiga was undertaken to provide guidance and baseline data for future references. Two field works were undertaken in August and November 2007 to collect the groundwater samples. Groundwater samples were collected from five representative wells at the low lying area of Pulau Tiga in order to study the in-situ parameters such as DO (dissolved oxygen), EC (electrical conductivity), TDS (total dissolved solids), pH, salinity and temperature. In general, groundwater in Pulau Tiga is moderate in conductivity (330 $\mu\text{S}/\text{cm}$ – 1005 $\mu\text{S}/\text{cm}$), and serves as a vital freshwater source to both tourists and local inhabitants. However, bacteriological analysis showed that the groundwater quality was poor, with fecal coliform counts exceeding the WHO permissible limits for drinking water. Through this study, human factor was to be blame for the fecal contamination coliform where the polluted ground water might be originated from sanitation facilities located too close to the wells. The occurrence of total and fecal coliform bacteria in counts suggests poor sanitary handling and warns of the potential presence of disease-causing organisms.

Keywords: *E. coli; groundwater; Pulau Tiga; water quality*

ABSTRAK

Sampel air bawah tanah telah diambil dari lima buah perigi di Pulau Tiga bagi mengkaji parameter fizikokimia serta biologi terpilih untuk memahami kualiti air secara umum di pulau tersebut. Penyelidikan perintis air bawah tanah di Pulau Tiga telah dijalankan untuk menyediakan satu garis panduan serta data asas untuk rujukan masa depan. Dua kerja persampelan telah diadakan pada Ogos dan November 2007 bagi mengambil sampel air bawah tanah. Sampel-sampel air bawah tanah telah diambil dari lima buah perigi di Pulau Tiga untuk memahami parameter in-situ air tanah seperti DO (oksigen terlarut), EC (kekonduksian elektrik), TDS (jumlah pepejal terlarut), pH, kemasinan dan suhu. Secara umum, air tanah di Pulau Tiga adalah sederhana daripada segi kekonduksiannya (330 $\mu\text{S}/\text{cm}$ – 1005 $\mu\text{S}/\text{cm}$), dan ia berfungsi sebagai sumber air tawar yang utama bagi menampung keperluan pelancong dan penduduk tempatan. Walau bagaimanapun, analisis bakteriologi menunjukkan kualiti air bawah tanah yang dicemari dengan jumlah koliform najis yang melebihi piawai WHO untuk kegunaan air minuman. Melalui kajian ini, faktor manusia merupakan pengaruh utama bagi pencemaran najis di mana air bawah tanah yang tercemar dipercayai berasal daripada kemudahan sanitasi yang terletak berhampiran dengan perigi. Kehadiran jumlah koliform dan koliform najis dalam kiraan menggambarkan pengendalian sanitasi yang lemah dan pada masa yang sama memberi kesedaran tentang potensi kewujudan organisma yang boleh menyebabkan penyakit.

Kata Kunci : *Air bawah tanah; E. coli; kualiti air; Pulau Tiga*

INTRODUCTION

Presently, groundwater of small island located in the tropical region, especially in Malaysia receives increasing stress including contribution from anthropogenic factors. In this regards, Pulau Tiga a well known touristic island experiences such a great influx of tourist annually. On coral islands and coastal areas of other islands such as Pulau Tiga, contamination by sewage can threaten the use of groundwater as a drinking water supply. This is especially

severe on small and low-lying islands, where surface water supplies are generally unavailable, and number of tourists is increasing ahead of centralised sewerage collection and treatment systems. On such islands soils are usually thin, and aquifers are highly permeable and can only be tapped at shallow depths without drawing in saline water. These factors lead to a high risk of microbiological and nitrate contamination of groundwater which can have serious and recurrent affects on the health of local communities which rely on the groundwater supply (Dillon 1997).

As stated by Rai and Sharman (1995), lack of sanitation, improper waste disposal, faulty well construction and lack of water source protection measures and increased groundwater contamination attributed to pollute groundwater consumption. Hence assessment of water is very crucial to safeguard public health and the environment. Furthermore, there is lack of studies done in this island to understand the groundwater quality in such conditions. Thus this study was conducted to assess the groundwater quality in the island and in order to provide baseline groundwater data and quality of water resource which is focal for future management options and references. This research focused mainly on selected physico-chemical parameter and bacteriology, specifically total coliform and fecal coliform in groundwater. Possible groundwater contamination caused by septic tank and underground leakage was also studied.

MATERIALS AND METHODS

STUDY AREA

Pulau Tiga is a group of small Malaysian islands in Kimanis Bay off the western coast of Sabah. Located between 5° 42' and 5° 43' and 115° 37' and 115° 39', South West of Kota Kinabalu. The island lies a distance of 55 km and 12 km North East from Klias peninsular (Figure 1). Pulau Tiga is the largest island in the midst of others covering a region of 725 hectares with length of approximately 5.2 km and width of 1.8 km (Sanudin et al. 1999). The land use of the study area is typically residential or undeveloped. At present, thousands of tourists visit Pulau Tiga annually. The number of tourist increase and concurrent demand for available water resources is a very well established fact. As a result, groundwater represents an important source of drinking water to the small island's community is currently threatened by a combination of over-abstraction and chemical and microbiological contamination (Reid et al. 2003). Pulau Tiga has an annual mean temperature of approximately 23°C-32°C. Most of its freshwater depends on precipitation.

Pulau Tiga has a distinguished tropical climate which is characterised by warm and humid air, and also a high mean annual precipitation rate of 2816.4 mm). A tidal channel can be noted during wet season that allows the mixing of seawater into the brackish mangrove swamp water. Geologically, the study area is part of Quaternary sedimentary terrain. Pulau Tiga is constituted by material of sedimentary origin that forms a chaotic accumulation of fluvial and volcanic materials located at the vent of a mud volcano. Therefore, the entire island is covered with a mud volcanic soil. This mud volcanic soil is essentially comprised of mixture incorporated with mud and shale. These stratigraphic units consist of different sediment types with age ranging from Quaternary to early Paleogen (Sanudin et al. 1999).

EXPERIMENTAL

The sampling area of the study is primarily restricted to the flat coastal plain of Larai-Larai to the chalet of Pulau Tiga National Park at the coastal lowland forest (Figure 1). For this study, groundwater samples were collected from 5 wells (100%) located on Pulau Tiga. The first sampling was conducted in August 2007 while the second in November 2007. The sampling wells are situated at the low elevation area of the island. Currently, there are only 3 production wells (PT1, PT2 and PT4) that are still constantly provide freshwater supply to the inhabitants on that island. The other two wells (PT3 and PT5) were temporary abandoned due to high salinity.

Polyethylene bottles that were soaked with 10 % HNO₃ acid wash and pre-rinsed with distilled water were used to store groundwater samples based on the methods described in APHA (1995). A total of 30 triplicate groundwater samples were collected by using Wildco Water Sampler. The samples were transported to the laboratory for immediate analysis (APHA 1995). All instruments were calibrated appropriately according to the calibration standards prior to the measurements. Statistical analyses were applied to the groundwater quality data using SPSS software version 15 in order to verify and describe the relationships between the various determinants.

PHYSICO-CHEMICAL PARAMETERS

In situ measurement was made for parameter such as temperature, electrical conductivity (EC), total dissolved solids (TDS), pH, dissolved oxygen (DO) and salinity using probe Eutech EcoScan, Oakton Cond., EC-TDS Scan, YSI 650 and Eutech Salttester, respectively. The samples were cooled at 4 °C and kept in a dark cooler box when transported to the laboratory. Groundwater samples were analysed immediately after sampling to obtain representative readings. Unfiltered and un-acidified samples were used in determining chloride (Cl⁻) concentration using argentometric (AgNO₃) as suggested by APHA (1995) in the Water Quality Laboratory of the School of Science and Technology, Universiti Malaysia Sabah, Malaysia. Nitrate (NO₃⁻) were filtered through a 0.45 cellulose membrane (Millipore) to remove suspended solids in the samples prior to detection using HACH (DR/2040) meter.

BIOLOGICAL PARAMETERS

The samples were enumerated by the membrane filtration technique modified from Standard Methods for The Examination of Water & Wastewater to determine the presence of total coliform and fecal coliform in groundwater. For coliform analysis, all glassware and tools were sterilized before usage by autoclaving for 20 minutes at 120°C and were decontaminated between samples by flaming. All contact points of laboratory were

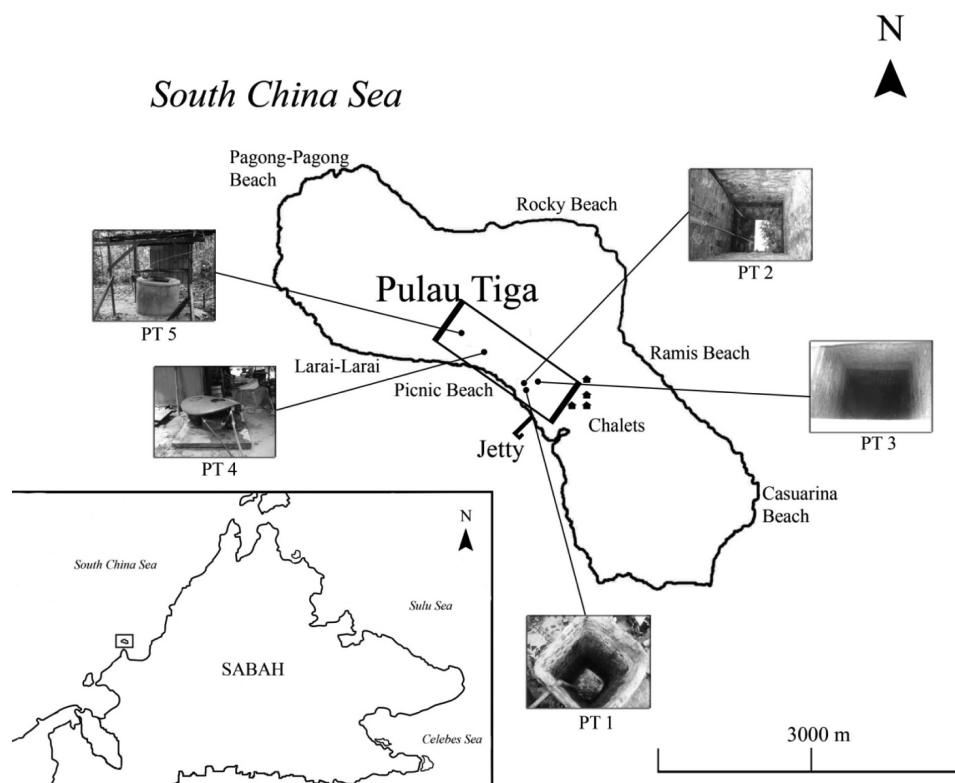


FIGURE 1. Location of the five sampling stations and production wells at Pulau Tiga, Sabah, Malaysia

sterilized by using ethanol 95%. Membrane Laury Sulfate broth was freshly prepared on the day before sampling. Glass sample bottles were wrapped by aluminium foil to prevent the penetration of sunlight and cooled to 4°C for preservation. Samples (100 mL) were filtered with WHATMAN 0.45 μm pore cellulose membrane. Then, the cellulose membrane was transfer to a specific germ-free bed gently soaked with membrane laury sulfate broth. The bed were enclose with aluminium Petri dish before insert into a Paqualab incubator for incubation at 37 °C chamber (for total coliform) and 44 °C chamber (for fecal coliform) for 24 hours incubation. Both analyses for total coliform and fecal coliform were based on colony forming unit (CFU) per sample. A direct count method on the number of bacteria colony was carried out. Red-pinkish colonies indicate coliform bacteria and they were subsequently counted. Owing to limited incubation space, only one sample was analysed per site.

RESULTS AND DISCUSSIONS

IN-SITU PARAMETERS

The *in-situ* parameters results for both sampling periods (August and November 2007) from 30 samples were averaged as shown in Table 1. In general, groundwater samples from Pulau Tiga shows slightly acidic to slightly alkaline condition, with a pH range between 6.84 to 7.35

and a median value of 7.02. The slight alkaline nature of groundwater may be due to the presence of fine aquifer sediments mixed with clay and mud (Laluraj et al. 2005). The groundwater temperature recorded was generally between 26.7 °C to 29.9 °C and with an average value at 28.3 °C. Groundwater in Pulau Tiga has low mineralisation which can be explained by the electrical conductivity (EC) measurement that varies from 861 μScm^{-1} to 1005 μScm^{-1} (August 2007) and 329 μScm^{-1} to 828 μScm^{-1} (November 2007). This noticeable variation in the measured EC is probably due to the dilution of groundwater by heavy precipitation (Mondal et al. 2007). This postulation is strongly supported by the results of one-way ANOVA test (a kind of variance analysis) that show significant difference ($p < 0.01$) between two different sampling seasons. The relatively wide ranges of EC values obtained indicate the significant of pumping activities which occurred on the island. It also indicates that the groundwater experienced different groundwater quality at different locations. Generally, the greater the amount of dissolved solids in the water, the greater is the water's conductivity. This was apparently supported by the correlation between both EC and TDS values which shows a strong positive correlation ($r = 0.994$, $p < 0.01$) as shown in Figure 2. According to Langeneggar (1990), the importance of EC is its measure of salinity, which greatly affects the taste and thus has a significant impact on the users' acceptance of the water as potable. Table 1 shows that all the groundwater samples are below the WHO (2004) limit of 1400 $\mu\text{S/cm}$.

TABLE 1. Summary of the *in-situ* results recorded in Pulau Tiga for both sampling campaigns*

	August 2007					November 2007					WHO Limit
	PT 1	PT 2	PT 3	PT 4	PT 5	PT 1	PT 2	PT 3	PT 4	PT 5	
pH	6.84	6.84	7.27	6.98	7.08	6.93	7.13	6.86	7.33	6.94	6.5-8.5
Temp. (°C)	28.80	28.80	28.60	29.90	29.80	27.70	27.70	27.60	27.40	26.90	-
DO (mg/l)	2.00	2.06	1.84	1.08	1.53	4.20	4.22	4.69	6.01	5.69	-
EC (µS/cm)	956.00	861.00	999.00	987.00	1005.00	817.00	828.00	505.00	786.00	330.00	1400.00
Salinity (ppt)	0.50	0.40	0.50	0.50	0.50	0.40	0.40	0.20	0.40	0.10	-
TDS (ppm)	476.00	430.00	499.00	490.00	502.00	412.00	414.00	253.00	353.00	165.00	-
Cl ⁻ (mg/l)	147.08	101.17	266.95	145.43	149.65	73.15	68.98	241.42	57.65	54.98	250.00
NO ₃ ⁻ (mg/l)	3.30	3.00	1.60	1.50	2.10	1.60	1.80	1.80	1.00	1.20	50.00

*Number of samples = 30

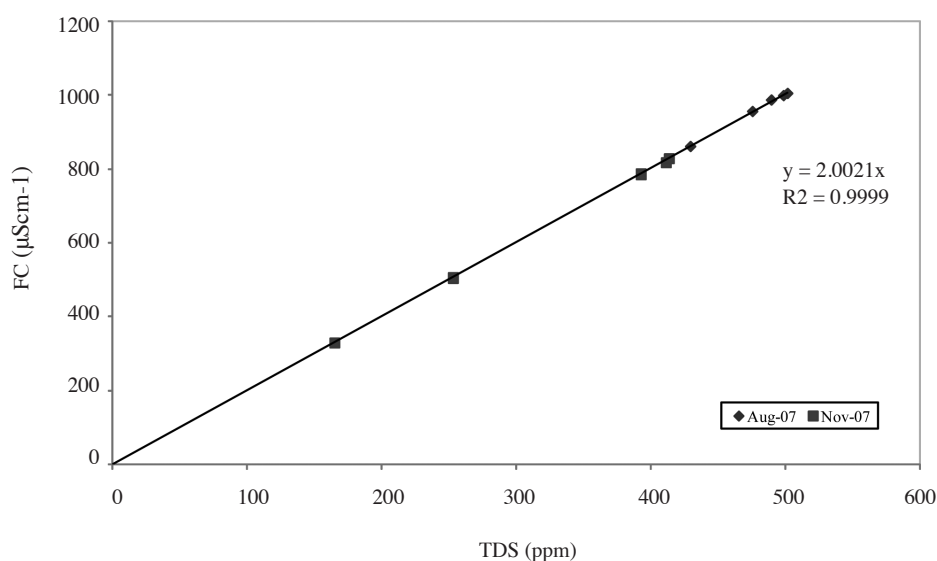


FIGURE 2. Conductivity (µS/cm-1) vs. TDS (in mg/l-1) plots for the studied groundwater

Total dissolved solids (TDS) varies from 164 mgL⁻¹ to 502 mgL⁻¹ in August 2007 and November 2007, respectively. As a general observation, lower TDS values were observed in November 2007 while higher TDS values were observed in August 2007 which explains the possibility of dilution effect during the wet periods. These data can be supported by the overall decrease in salinity and electrical conductivity values during the

second sampling trip in November 2007. Dissolved oxygen (DO) concentration ranges between 1.08 mgL⁻¹ to 2.06 mgL⁻¹ in August 2007. There was a slight increase in concentration of DO during wet season (November 2007) which ranges from 4.20 mgL⁻¹ to 6.12 mgL⁻¹. *In situ* parameters measurement shows a relatively low salinity in groundwater of Pulau Tiga with a range from 0.1 ppt to 0.5 ppt.

ANION CONSTITUENTS

Chemical analysis results indicate that the concentration of chloride in 20 % of the analysed samples ($n = 30$) exceeded the value of 250 mgL^{-1} recommended by WHO (2004) as the maximum permissible limit for drinking water. PT3 recorded Cl^- concentration of 266.95 mgL^{-1} and 241.42 mgL^{-1} in August 2007 and November 2007, respectively, which represents the highest chloride concentration among all sampling stations. High chloride concentration may be due to the proximity of the well to a tidal channel and the poor muddy sediments present in the aquifer system which further infers saline intrusion. Study on nitrate was being conducted and excessive levels of nitrate in drinking water can cause serious illness and even death. In general, nitrates have the potential to cause shortness of breath, blue babies syndrome in infant's diuresis, increased starchy deposits and haemorrhaging of the spleen (USEPA 2004). It can be considered as providential because the nitrate concentration shows a relatively low value with range from 3.70 mgL^{-1} to 0.80 mgL^{-1} for both sampling periods (Figure 3) which is considered far below the WHO permissible limit of 50 mgL^{-1} (WHO 2004).

BIOLOGICAL PARAMETERS

Preliminary survey of biological samples (total coliform and fecal coliform) was examined for both August and November 2007 sampling periods. Five of the wells (100%) for both sampling events tested positive for total coliform bacteria. In general, total coliform levels were higher than fecal coliform levels for all sources. Some of the total coliform are most likely the result to benign bacteria that do not reflect sewage contamination (Atherholt et al. 2003). Therefore, a positive total coliform test should be followed by fecal coliform test to confirm contamination. It is further assumed that the fecal coliform concentration adequately reflects the presence of all microbial pathogens (Styenberg et al. 1995). Coliform bacteria were detected at moderate levels ($< 50 \text{ CFU}/100 \text{ mL}$) in 3 of 5 wells sampled in August 2007.

When resampled in November 2007, bacteria were detected at lower level ($< 20 \text{ CFU}/100 \text{ mL}$) in 3 of 5 wells as shown in Table 2. The colony forming unit (CFU) is a parameter which indicates the presence of coliform bacterial pollution in the water samples. The presence of coliform also indicates the possibility of presence of other pathogenic microorganisms and further indicates the possibility of contamination of the water source with sewage (Hosetti & Kumar 2002). Potential sources of contamination in the study area are human waste, animal fecal waste and the septic system.

According to WHO (2004) guidelines, fecal coliform and total coliform should not be detectable in any water intended for drinking. Nevertheless, the present study revealed a moderate incidence of fecal coliform, which ranges from 0 to 40 CFU (colony forming unit) per 100 mL sample, indicating relatively poor sanitary condition and improper waste disposal (Laluraj et al. 2005).

In Pulau Tiga, although the wells are closed and well managed it still showed positive in bacterial count. This might be associated with the occurrence of leakage in nearby septic tank which is the highest possible source for fecal contamination. Comparatively, lower coliform results were found at PT 1 (total coliform – 27 CFU/100 mL, fecal coliform – 5 CFU/100 mL during August 2007; total coliform – 12 CFU/100 mL, fecal coliform – 0 CFU/100 mL during November 2007) and PT 2 (total coliform – 43 CFU/100 mL, fecal coliform – 9 CFU/100 mL during August 2007; total coliform – 2 CFU/100 mL; fecal coliform – 0 CFU/100 mL during November 2007) as shown in Table 3 and 4, respectively. This was due to the fact that both sampling stations were situated far (approximately 30 m) from existing public toilets as well as septic tank. However, moderate concentrations of fecal coliforms were occasionally found at PT4 and PT5 which is located in relatively close distance (approximately 15 m) to the toilets and septic tank. These phenomena might be attributed to sewage movement through cracks, root channels, and fissures (Hagedorn 1984).

Because there are no wild animals greatly present, thereby human factor is most likely to be blamed for the contamination and harm caused to the groundwater and the fresh water reserve in Pulau Tiga. Because the presence of total and fecal coliform in water indicates fecal contamination, facilitated by the proximity between the wells and toilets/septic tank, the study thereby suggests that the toilets/septic tank are the major source of contamination of the wells with fecal matter. Effluents from point-like sources such as septic tank are regularly considered as the main sources of contamination of groundwater (Woods 1990). Furthermore, this evidence explains increased lateral separation between the source of pollution and groundwater supply reduces the risk of fecal pollution (ARGOSS 2001). In fact thin soil filtration effect and distance of septic tank does play great influence in fecal contamination in small island (Anthony 1992).

Through this study, the locations and concentration of bacteria for both sampling campaigns have varied widely. Based on the bacteria concentration and the distribution of the affected wells, a single source of bacteria is not believed to have affected all five wells. Rather, it is more likely that multiple sources of bacteria affected these wells. The presence of fecal coliform in groundwater indicates a potentially dangerous situation, and requires immediate attention before the situation gets worse.

STATISTICAL ANALYSIS

SPSS correlation test were used to determine the existence of the relationship among the parameters. The dataset was separately examined for two sampling periods (August 2007 and November 2007) to describe the general behaviour. Correlation coefficient matrix between the examined physico-chemical parameters, which was calculated using linear regression analysis, is shown in Table 3 and Table 4. It was noted that the correlation coefficients between total

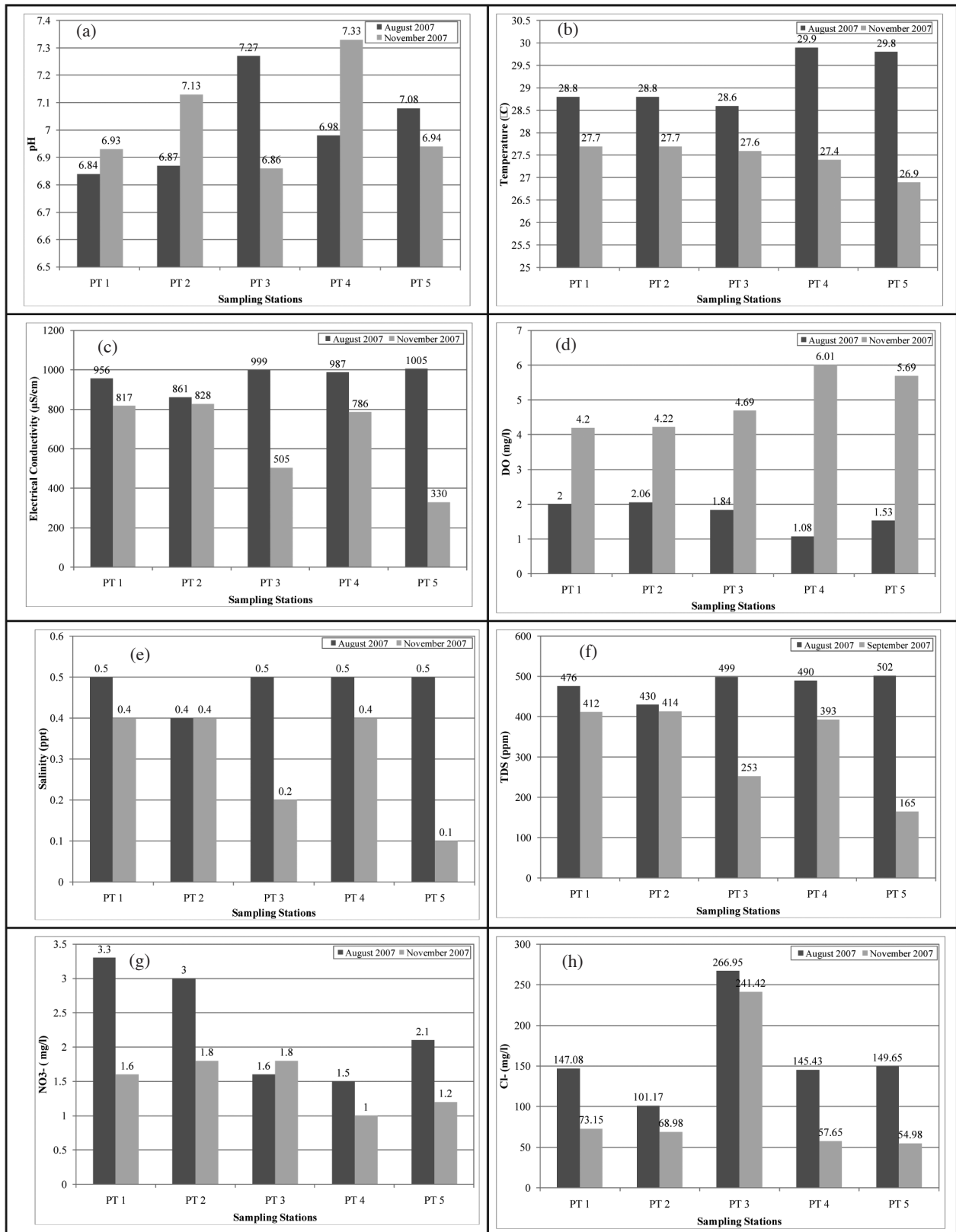


FIGURE 3. Variations of the physico-chemical parameter for both sampling periods (August 2007 and November 2007) (a) pH, (b) temperature, (c) electrical conductivity, (d) DO, (e) Salinity, (f) TDS, (g) NO₃⁻ and (h) Cl⁻

TABLE 2. Total and fecal coliform (August and November 2007)

Sampling Stations	August 2007		November 2007	
	Total Coliform (CFU/100ml)	Fecal Coliform (CFU/100ml)	Total Coliform (CFU/100ml)	Fecal Coliform (CFU/100ml)
PT 1	27	5	12	0
PT 2	43	9	2	0
PT 3	64	17	30	16
PT 4	64	15	18	12
PT 5	50	7	60	40

TABLE 3. Correlation coefficient matrix of analyzed parameters for August 2007

	pH	Temp	EC	DO	Salinity	TDS	NO ₃	Cl	T.Coli	F.Coli
pH	1.000	0.584 ^a	0.000**	-0.058	0.196	0.000**	0.002**	0.141	0.000**	0.004
Temp	-0.154	1.000	0.585	0.007**	0.518	0.585	0.408	0.224	0.574	0.463
EC	0.797	0.153	1.000	0.004**	0.003**	0.000**	0.032*	0.206	0.029*	0.476
DO	-0.500	-0.667	-0.697	1.000	0.003**	0.004**	0.001**	0.217	0.003**	0.277
Salinity	0.354	0.181	0.705	-0.707	1.000	0.003**	0.113	0.004**	0.184	1.000
TDS	0.798	0.153	0.994	-0.698	0.705	1.000	0.030*	0.195	0.029*	0.476
NO ₃	-0.735	-0.231	-0.556	0.746	-0.427	-0.560	1.000	0.089	0.000**	0.001**
Cl	0.399	-0.334	0.347	-0.339	0.696	0.354	-0.454	1.000	0.076	0.108
T.Coli	0.821	0.158	0.562	-0.718	0.363	0.563	-0.923	0.471	1.000	0.000**
F.Coli	0.700	-0.205	0.199	-0.300	0.000	0.199	-0.751	0.432	0.872 ^b	1.000

^a Value in the upper triangle of the matrix is significant value ($p < 0.01$ ** and $p < 0.05$ *)

^b Correlation values (in lower triangle)

TABLE 4. Correlation coefficient matrix of analyzed parameters for November 2007

	pH	Temp	EC	DO	Salinity	TDS	NO ₃	Cl	T.Coli	F.Coli
pH	1.000	0.872 ^a	0.050*	0.305	0.003**	0.079	0.305	0.060	0.039*	0.068
Temp	0.045	1.000	0.000**	0.000**	0.010**	0.000**	0.004**	0.010**	0.000**	0.000**
EC	0.514	0.789	1.000	0.018*	0.000**	0.000**	0.054	0.370	0.000**	0.000**
DO	0.284	-0.855	-0.601	1.000	0.224	0.012*	0.002**	0.015*	0.019*	0.007**
Salinity	0.714	0.643	0.892	-0.334	1.000	0.000**	0.479	0.649	0.000**	0.000**
TDS	0.468	0.855	0.964	-0.632	0.889	1.000	0.092	0.339	0.000**	0.000**
NO ₃	-0.284	0.693	0.507	-0.733	0.198	0.450	1.000	0.005**	0.055	0.078
Cl	-0.496	0.641	0.250	-0.614	0.128	0.265	0.681	1.000	0.388	0.283
T.Coli	-0.538	-0.794	-0.997	0.597	-0.894	-0.961	-0.504	-0.240	1.000	0.000**
F.Coli	-0.483	-0.841	-0.972	0.663	-0.918	-0.969	-0.469	-0.297	0.975 ^b	1.000

^a Value in the upper triangle of the matrix is significant value ($p < 0.01$ ** and $p < 0.05$ *)

^b Correlation values (in lower triangle)

and fecal coliform were significant ($r = 0.872$, $p < 0.01$ during August 2007; $r = 0.975$, $p < 0.01$ during November 2007), indicating that there were strong relationships between both biological parameters. A negative correlation was found between total coliform ($r = -0.923$; $r = -0.504$) and fecal coliform ($r = -0.751$; $r = -0.469$) with respect to nitrate in August 2007 and November 2007, respectively. The minus indicates that the increase in nitrate causes decrease in total or fecal coliform count. This statement can be explained by (Browne 2002), reduction of nitrate to the gaseous state of nitrogen in oxygen depleted bottom sediment may be facilitated by bacteria through a process known as denitrification. The temperature was negatively correlated ($r = -0.667$ in August 2007; $r = -0.855$ in November 2007) with dissolve oxygen (DO) indicating that an increase in DO is generally linked to a decrease in temperature. On the other hand, EC have a strong to a very strong positive correlation ($r = 0.705$ in August 2007; $r = 0.892$ in November 2007) with salinity, indicating that higher EC value often accompanied by a higher salinity. The result was corroborated by a high positive correlation ($r = 0.994$ in August 2007; $r = 0.964$ in November 2007) between EC and TDS.

Generally, an increase in temperature causes a decrease in the bacterial count and the same goes to pH and salinity as well where the increase in salinity reduces the bacterial count (Baleux & Troussellier 1994; Crysup & Mott 2001; Flint 1987). However, this study showed that no significant data relationships were obtained between those parameters and the bacteria count. Referring to the SPSS output can be said that none of the parameters are related to fecal bacteria growth. This might be due to the small sample size and variation that can be used as comparison to be made as a conclusion. Other influencing factors should be taken into consideration include cations, anions, presence of metals, organic and inorganic substances (Aislabie et al. 2001; Francy Donna et al. 2000).

In this study, analysis of variance (ANOVA) has been used to show significant change in certain chemical composition of groundwater when is sampled at different climatic conditions. It can be observed that the concentration of anions generally decreased in November 2007 during rainy season. This decrease may be due to the high contribution of rechargeable rainwater which dilutes the concentration of the existing groundwater within the aquifer. ANOVA analysis, pH, temperature, EC, DO, salinity, TDS and NO_3^- , showed significant variations between dry and wet periods. Conversely, pH ($r = 0.634$) Cl^- ($r = 0.213$) and fecal coliform ($r = 0.471$) do not shows significant variations between seasons.

CONCLUSION

The study showed that overall the groundwater quality of Pulau Tiga was slightly deteriorated with respect to measured the physico-chemical parameters. The main possible source of chloride ions presents in the groundwater of Pulau Tiga may be saline intrusion and other marine

sources. A high rainwater contribution to the aquifer leads to a decrease in the chloride concentration due to dilution processes. It can be concluded that most of the well in Pulau Tiga were fecally contaminated. The presence of indicator organisms in the water samples collected from the wells indicates that the coliforms might be originated from fecal matter in the toilet/septic tank that facilitated by the very short distance between the toilets and the wells. It was evidenced by moderate values and presence of coliforms alarming situation from the public health point of view. This situation posed a health hazard to the residents and tourists as they are greatly prone to water-borne diseases such as diarrhea, typhoid, cholera and so on.

Accordingly, recommendations can be made to the local authorities to take suitable control measures for drinking water source. The distance between the wells and the sanitation facilities was estimated to be generally short with nearly 60% of the toilets/septic tank estimated to be at a distance of less than 15 m from the wells. Apparently, this raises the risk of contamination of the water sources as coliforms migrate from the source to the wells. Hence, this study suggests that there should be an adequate lateral separation of the groundwater. Based on the results, 80% of the sample analysed comply with the WHO water standards for drinking water.

If microbiological parameters are taken into account, such as total coliform and fecal coliform, then the analysed groundwater would not be suitable for human consumption without prior treatment. Therefore, none of the wells studied met the WHO requirements for water intended for drinking. Since this is a baseline study, it is recommended that groundwater analysis be carried out frequently to monitor the rate and kind of contaminations. Therefore, based on this study, it is highly recommended that the local authorities should take suitable control measures for drinking water source. As an outcome of this research, it would be wise that all water should be treated with chlorination or boiling before being used (Stambuk-Giljanovic 2005). For long term planning purposes, an installation of small-scale water treatment plant should be taken into consideration.

ACKNOWLEDGEMENTS

This research was supported by the Ministry of Higher Education, Malaysia through the Fundamental Research Grant No. FRG0050-ST-1/2006. Permission from the Sabah Park Trustees for the study site is acknowledged.

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Received: 25 June 2009

Accepted : 19 October 2009