Characteristics of groundwater well quality using bivariate analysis: A case study at USM Engineering Campus, Penang

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Abstract. This study was carried out to determine the water quality at USM tube well based on the physico-chemical and biological characteristics. In this paper, the groundwater sample was extracted from the USM tube well through pumping process. The sample was collected twice a month for one year (n=24). Water quality analysis was conducted by in-situ and laboratory testing. Ten (10) water quality parameters such as turbidity, colour, total dissolve solid (TDS), conductivity, pH, total hardness, heavy metal (Fe & Mn), total coliform and E-Coli were analysed and compared the result with Raw and Drinking Water Quality Requirement established by Malaysian Standard (MS2320). The relationship between parameters was also analysed statistically using Spearman’s correlation coefficient ($r^2$). Result shows that Fe has a strong positive correlation with Mn and conductivity. The correlation between conductivity- Fe and conductivity- Mn have a strong positive correlation with $r^2$ between 0.6 and 0.79. This indicates that cation minerals in soil, sediment and rock such as Fe and Mn leach out into groundwater and thus contribute to the electrical conductivity of groundwater. Moreover, Mn demonstrated a significant positive correlation with TDS and conductivity. The strong relationship between Mn-TDS ($r^2 = 0.77$) and Mn- conductivity ($r^2 = 0.75$) respectively, suggested that the concentration of Mn in USM tube well was influenced by dissolution minerals in groundwater. On the contrary, the correlation between turbidity-hardness, turbidity- E-coli and turbidity-total coliform showed a very weak positive ($r^2 < 0.2$) and negative ($r^2 < -0.2$) significance, which indicates that turbidity was not significant with all parameters present in USM tube well. Overall, it can be concluded that the water quality from USM tube well is not recommended for drinking, which did not comply the Malaysian standard of drinking water. However, it can be used for other purposes such as irrigation and industrial activities.

1. Introduction

The abundance of untapped groundwater may become a significant alternative of water source in Malaysia, which is expected to reduce the occurrence of water scarcity problems in this country. However, rapid urbanisation and sophisticated industrialisation that led to an increase in population have a significant impact on water demand. Agricultural activities including cultivation plant have also attributed to high water demand. Groundwater may be utilised for these purposes to overcome water scarcity problem.
Currently, the use of groundwater is limited to some areas in Kelantan, Terengganu, Pahang, Perlis, Selangor, Labuan and Sarawak. However, the significant impact on its usage is the presence of various type of pollutants in the groundwater. Human activities have led to groundwater contamination and contributed to the major issues that adversely affected drinking water.

One of a major concern in addressing the problems of groundwater pollution is high concentration of heavy metal such as Fe and Mn. These metals enter groundwater during the weathering process of soils, sediments and minerals [1]. It is also a common problem in other countries such as Northern Greece [2], Bangladesh [3], Netherlands [4], Yemen [5] and Vietnam [6]. Minerals content in soil, sediment and rock such as Ca, Mg, Fe and Mn may affect the quality of groundwater. Besides, poor sanitation and sanitation facilities especially for those living in the rural areas contributed to high concentration of bacteria in the groundwater. The presence of bacteria in groundwater may cause waterborne diseases. High risk of waterborne disease occurred due to human and animal faecal wastes that infiltrate into groundwater. Human faecal sources include septic tank effluent and leakage of wastewater collection pipes, while animal source includes farm animals and pets [7]. Therefore, monitoring of groundwater quality is important part to present the overall water quality in the certain time and location. Moreover, the purpose of groundwater monitoring and characteristic is to ensure the quality of groundwater follow the environmental standard and guideline depends on the use of water.

Besides, in the study area, there is a groundwater well located at the School of Civil Engineering, USM Engineering Campus, Pulau Pinang. However, there is no long term characterisation study undertaken and reported to date. The present study attempts to determine and analyse statistically the quality of groundwater at USM tube well. In this study, the relationships of each water quality parameters were correlated using bivariate analysis.

2. Methodology

2.1 Groundwater sampling
In this study, the groundwater sample was collected from USM tube well which is located at the School of Civil Engineering, USM Engineering Campus (5° 08’ 50.5” N, 100° 29’ 34.7” E) as shown in figure 1. The sample was collected every two weeks from February 2015 until Jan 2016 (n= 24). Before collecting groundwater sample, the well was purged 2 to 3 well volumes using an electric water submersible pump to remove stagnant water from the tube well and to ensure the water withdrawn is from the aquifer. After completing the purging process at a constant time, then the sample was collected in a designated container and preserved according to the Standard Method for the Examination of Water and Wastewater.

2.2 Water quality analysis
Water quality analysis was conducted by in-situ and laboratory testing. Field parameters such as conductivity, pH and TDS were measured using a multi-parameter instrument (YSI Professional Plus). Laboratory analyses involving parameters colour, turbidity, total hardness, heavy metals (Fe and Mn) and coliform bacteria were conducted at the Environmental Engineering Laboratory, School of Civil Engineering, USM. Table 1 shows the instrument and method used for the characteristic study.
Figure 1. Sampling location at USM tube well (5° 08’ 50.5” N, 100° 29’ 34.7” E).

| Parameter   | Instrument                      | Model           | Method                  |
|-------------|---------------------------------|-----------------|-------------------------|
| Turbidity   | Turbidity meter                 | Hach 2100N      | EPA Method 180.1        |
| Colour      | Spectrophotometer               | Hach DR2800     | APHA Method 2120        |
| TDS         | Muti-parameter instrument       | YSI Professional Plus | -                        |
| pH          | Ph meter                        | TRANS Instrument | -                       |
|             |                                 | HP3040          |                         |
| Conductivity| Muti-parameter instrument       | YSI Professional Plus | -                        |
| Total hardness| EDTA titration                  | -               | SM 2340C                |
| Fe          | Atomic absorption spectrophotometer | Perkin Elmer A.Analyst 800 | APHA Method 3111B    |
| Mn          | Atomic absorption spectrophotometer | Perkin Elmer A.Analyst 800 | APHA Method 3111B    |
| E-Coli      | IDEXX Colilert test kit         | -               | -                       |
| T. Coliform | IDEXX Colilert test kit         | -               | -                       |

2.3 Bivariate analysis
Water quality monitoring and characteristic data were sorted and analyzed using Microsoft Excel 2013 and Minitab 17 software. Bivariate analysis using Spearman correlation was carried out for physical, chemical and microbial characteristics for USM tube well. This analysis was used to measure the strength of association and relationship between water quality parameters that have been analyzed in this study. The mathematical expression of Spearman’s correlation is shown in equation (1).
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\[ r_{\text{spearman}} = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \]  

Where \( d_i \) represents the difference between two ranks of each observation and \( n \) is the number of observations. The value of the Spearman correlation coefficient between +1 and -1 describes positive and negative linear correlation.

3. Result and discussion

There are several parameters such as conductivity, TDS and pH were measured on site, while other parameters such as turbidity, colour, total hardness, heavy metals, and coliform bacteria were tested in the Environmental Laboratory, School of Civil Engineering, USM, immediately after reaching the laboratory. The water quality characteristics in terms of their physical, chemical and biological were compared with Raw and Drinking Water Quality Requirement established by Malaysian Standard [8] as listed in table 2.

### Table 2. Summary result of USM tube well (n= 24).

| Parameters      | unit | Min   | Max   | Average | Raw water quality std | Drinking water quality std |
|-----------------|------|-------|-------|---------|------------------------|---------------------------|
| **Physical**    |      |       |       |         |                        |                           |
| Turbidity       | NTU  | 1.123 | 40.5  | 17.1    | 1000                   | 5                         |
| True color      | PtCo | 76    | 286   | 144.6   | 300                    | 15                        |
| **Chemical**    |      |       |       |         |                        |                           |
| TDS             | mg/L | 5620  | 8021  | 6325    | 1500                   | 1000                      |
| pH              | -    | 6.1   | 6.77  | 6.39    | 5.5 -9.0               | 6.5 - 9                   |
| Conductivity    | uS/cm| 8897  | 13258 | 10357   | 1000                   | NA                        |
| Total hardness  | mg/L | 1260  | 1770  | 1512    | 500                    | 500                       |
| Fe              | mg/L | 0.011 | 10.646| 1.229   | 1.0                    | 0.3                       |
| Mn              | mg/L | 0.322 | 1.039 | 0.559   | 0.2                    | 0.1                       |
| **Biological**  |      |       |       |         |                        |                           |
| E-Coli          | MPN  | 0     | 1.5   | 0.104   | 5000                   | Absent                    |
| T. Coliform     | MPN  | 0     | 2419.6| 158.35  | 5000                   | Absent                    |

3.1 Physical characteristic

Turbidity is a physical parameter in measuring the cloudiness of water sample caused by large and small particle present in water. The value of turbidity determined at USM tube well was in the range of 1.123 – 40.5 NTU with the average value of 17.1 NTU, which exceeded the standard level for drinking. Turbidity increases with the increase in suspended solids (SS) and organic matter concentration in groundwater [9]. In addition, the high turbidity in the groundwater of USM tube well was due to the presence of natural mineral compounds such as calcium carbonate in the groundwater. High turbidity may also be contributed by contamination from the surroundings, which attributed by the activities during construction of the campus in the year 1999-2000.

Besides, high colour concentration was obtained from USM tube well ranges from 76 PtCo – 286.5 PtCo. This was possibly due to algae growth that increased the organic activity in the groundwater. Within the USM tube well, an excessive amount of nutrients from decaying vegetation, animal waste and fertilizers runoff provided sufficient phosphorus and nitrogen amount for the growth of algae. Its oxygen level will also decrease since the well water is in stagnant position. The presence of even a slight amount of oxygen can contribute to the formation of new life cycle of algae. Moreover, the presence of soluble minerals such as Ca\(^{2+}\), Mg\(^{2+}\), Fe\(^{2+}\) and Mn\(^{2+}\) may also attribute to high colour in USM tube well. These mineral ions dissolved from sediment, soil particles and rock, which travel along the mineral surface in the aquifer.
3.2 Chemical characteristic

Chemical characteristic such as TDS, pH, conductivity, total hardness and heavy metals were analysed in this study. TDS determines the suitability of water for drinking and irrigation purposes [10]. Higher TDS is attributed to the more cation and anion, thus increasing the electrical conductivity in groundwater [11]. TDS for USM tube well samples was in the range of 5620 mg/L - 8021 mg/L with a mean value of 6325.67 mg/L. A prolonged contact between the groundwater and these minerals will result in higher content of dissolved minerals due to its extended reaction with those minerals. Moreover, based on the Nibong Tebal landuse classification, the major portion of the area was found to be of the agricultural land, which greatly contributed to the high TDS content in the groundwater of the USM tube well. In a similar case in Malacca State, a high TDS concentration value in groundwater which was due to the percolation of agricultural activities [12].

Besides, pH is a parameter used to determine the biological activities that can occur for the organisms in natural groundwater [13]. In the present study, pH was monitored on-site using the multi-parameter probe (Model: YSI Professional Plus) and the average of pH 6.39 was recorded for USM tube well. Therefore, pH for well in this study area are acceptable for raw water, but not suitable for drinking water purposes and thus require pH adjustment to comply with the standard.

Total hardness is a chemical parameter used to classify soft to very hard water according to the hardness concentration as mg/L of CaCO$_3$. From the result, it was found that the mean concentration of hardness at USM tube well was 1,512 mg/L as CaCO$_3$. It was indicated that the water from the USM tube well classified as very hard, which contains a very high concentration of total hardness. The hardness concentration was high due to the movement and infiltration of water through soils and rocks, which tend to dissolve the small amounts of naturally-occurring minerals that present along the way which were then carried along into the groundwater. In the USM tube well, water hardness occurred as a result of the weathering of sedimentary rock, limestone and calcium bearing minerals which were proved by the geological map of Peninsular Malaysia.

In groundwater, highly elevated Fe and Mn are serious problem causing the reddish colour in water. During the pumping process, the reaction of dissolved Fe and Mn caused oxidation to Fe and Mn hydroxide [14]. In the present study, this study areas have a problem with elevated Fe and Mn in groundwater. As reported in table 2, the average concentration of Fe and Mn were 1.229 mg/L and 0.559 mg/L respectively. High Fe concentration in the USM tube well was caused by dissolved Fe originated from sediment, soil particle and bedrock. Fe can exist as Fe$^{2+}$ ions in its reduction state or Fe$^{3+}$ ions in the oxidized state. In reduced state, Fe is more soluble compared to that in the oxidized state, which can be formed into iron oxide (Fe$_2$O$_3$) and iron hydroxide (Fe[OH]$_3$) minerals. Therefore, high concentrations of Fe and Mn will be found present in the groundwater.

The occurrence of Mn in groundwater is possibly due to several factors such as water chemistry, rock geochemistry and microbiological activity. In the groundwater of the USM tube well, the presence of total coliform and E-Coli can play an important part in the Mn mobilization and concentration enhancement. The enzymatic catalysis of the oxidation and reduction of Mn or the altering of the Eh and pH conditions may influence the Mn concentration and its speciation.

3.3 Biological characteristic

Groundwater contaminated by microbial is a serious problem attributed to waterborne disease. The result shows that the mean concentration of total coliform was 158 MPN/100 mL of sample while the E-Coli concentration was 0.1 MPN/100 mL of sample. High concentration of total coliform and E-Coli at USM tube well was due to surface runoff from palm effluent and cow farm effluent near to the well that infiltrated the groundwater. Daud et al. 2017 reported cow dung and municipal wastewater effluent contaminating the tube well at Gangapur village, which caused diarrhoea especially for infant and children. Both coliform bacteria exceeded drinking water standard by MS2320 (2010). The presence of total coliform and E-Coli indicated that the abstracted water from USM tube well is not recommended as drinking.
3.4 Statistical analysis of Spearman Correlation

Table 3 showed the analysis result of characteristic parameters at USM tube well using Spearman’s correlation coefficient. Fe has a significant correlation with Mn, conductivity, TDS, colour and hardness. In addition, Fe showed a strong positive correlation with Mn and conductivity. Medium positive correlation can be observed between Fe and TDS, colour and hardness. Fe originated from soluble minerals has also affected the colour in USM tube well. In addition, the correlation between conductivity- Fe and conductivity- Mn have a strong positive correlation with r² between 0.6 and 0.79. This indicates that cation minerals in soil, sediment and rock such as Fe and Mn leach out into groundwater and thus contribute to the electrical conductivity of groundwater. According to the bore log USM tube well design, the oxide minerals of Fe were found 35m below water table. Besides, Mn demonstrated a significant positive correlation with conductivity and TDS. The strong relationship between Mn-TDS and Mn- conductivity with the positive r² value of 0.769 and 0.754, respectively, suggested that the concentration of Mn in USM tube well was influenced by dissolution minerals in groundwater. The result showed a very strong linear positive correlation between TDS and conductivity with a correlation coefficient value of 0.816. The high conductivity was due to the presence of minerals in the soil and leaching into groundwater. On the contrary, the correlation between turbidity-hardness, turbidity- E-coli and turbidity-total coliform showed a very weak positive (r² < 0.2) and negative (r² < -0.2) significance, which indicates that turbidity was not significant with all parameters present in USM tube well.

Table 3. Spearman correlation coefficient matrix of water quality parameters in USM tube well (n = 24)

|       | Fe    | Mn    | conductivity | TDS   | pH   | turbidity | colour | Hardness | E-Coli |
|-------|-------|-------|--------------|-------|------|-----------|--------|----------|--------|
| Fe    | 1     |       |              |       |      |           |        |          |        |
| Mn    | 0.724*| 1     |              |       |      |           |        |          |        |
| conductivity | 0.603*| 0.754*|              |       |      |           |        |          |        |
| TDS   | 0.598*| 0.769*| 0.816*       |       |      |           |        |          |        |
| pH    | 0.103 | -0.042| -0.125       | -0.095|      |           |        |          |        |
| turbidity | 0.005 | 0.088 | -0.146       | -0.159| 0.147|           |        |          |        |
| colour | 0.528*| 0.365 | 0.164        | 0.299 | 0.157| 0.152     |        |          |        |
| Hardness | 0.535*| 0.363 | 0.338        | 0.199 | -0.199| -0.172    | 0.276  | 1        |
| E-Coli | 0.043 | 0.105 | -0.063       | 0.391 | 0.276| -0.187    | 0.325  | -0.348   | 1      |
| T.Coliform | 0.206 | -0.138| -0.126       | 0.104 | 0.304| -0.042    | -0.049 | -0.466   | 0.481  |

4. Conclusion

As a conclusion, the results have shown that water quality from USM tube well was not recommended as drinking water, which not comply with Malaysian Standard of Drinking Water Requirement due to high organic content in the groundwater. Water sampling from USM tube well is not recommended to be used for future study. This is due to the results obtained which indicated that the groundwater extracted from the well was contaminated. However, it is preferable to recommend for water treatment before being used for other purposes such as agricultural and industrial activities. In addition, the results also show that concentration of Fe was strongly positively correlated with Mn (r² = 0.724) and conductivity (r² = 0.603). The result signifies that the presence of cation minerals in soils, sediment, and rock leach out into groundwater and thus contribute to the electrical conductivity of groundwater.

Acknowledgments

This study was financially supported by Universiti Teknologi MARA, Cawangan Pulau Pinang, Universiti Sains Malaysia, Engineering Campus, Pulau Pinang and also supported by Ministry of
Education Malaysia for the Long-term Research Grant Scheme (LRGS) under the Protection of Drinking Water for Society: Source of Abstraction Treatment

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