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Quantity and Quality of Groundwater in Fractured Metasedimentary Rocks of the West Coast of Peninsular Malaysia

(Kualiti dan Kuantiti Air Bawah Tanah di batuan Metasedimen Terekah Pantai Barat Semenanjung Malaysia)

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ABSTRACT

Groundwater in fractured metasedimentary rock in Malaysia is a potential source of water for drinking and industrial uses. Industries including agricultural processing, mineral water bottling, manufacturing and golf courses pumped the water from the underlying fractured rocks. Fifty eight tubewells belong to private companies operating in various places in West Coast of Peninsular Malaysia were evaluated for their yield and quality of water. Rotary percussion methods were used for the drilling to a maximum depth of 200 m. The productivity of the wells and the characteristics of the aquifer were evaluated by pumping test using both the constant discharge rate and steps drawdown methods. The average yield of the wells at allowable drawdown of 40 m was found to be 416 m^3 per day. Results from water quality analysis indicated that the water was fresh with an average total dissolved solids (TDS) concentration of 101 to 150 mg/L. The hardness of the water varies from as low as 13 mg/L to a maximum of 353 mg/L. On the average, the water was moderately hard with the average hardness value of 80 mg/L. The water facies of the groundwater was found to be of calcium-sodium-bicarbonate water.

Keywords: Fractured metasedimentary rock; groundwater productivity; tubewell; water quality; water supply

ABSTRAK

Air bawah tanah di dalam batuan metasedimen di Malaysia yang terekah adalah sumber air berpotensi untuk air minuman dan kegunaan industri. Industri pertanian, pembotolan mineral air, pembuatan dan padang-padang golf adalah di antara industri yang mengambil air tersebut daripada batuan terekah. Sebanyak lima puluh lapan telaga tiub kepunyaan syarikat-syarikat swasta yang beroperasi di beberapa tempat di pantai barat Semenanjung Malaysia telah diperiksa tentang penghasilan dan kualiti airnya. Penggerudian dengan kaedah putaran tekanan udara telah digunakan untuk membina telaga sehingga kedalaman maksimum 200 m. Produktiviti telaga tiub dan ciri-ciri akuifernya telah dinilai dengan kaedah ujian pengepaman menggunakan kadar aliran dan surutan berperingkat. Purata pengeluaran air dari telaga-telaga pada surutan 40 m yang dibenarkan ialah 416 m^3 sehari. Keputusan daripada analisis kualiti air menunjukkan bahawa air tersebut ialah air tawar dengan purata jumlah kepekatan pepejal-pepejal terlarut sebanyak 101 hingga 150 mg/L. Kekerasan air itu berubah daripada serendah 13 mg/L hingga ke tahap maksimum 353 mg/L. Secara purata, air tersebut mempunyai kekerasan dengan nilai puratanya adalah 80 mg/L. Fasis air dari sumber batuan metasedimen terekah didapati tergolong dari jenis air kalsium natrium bikarbonat.

Kata kunci: Batuan metasedimen terekah; bekalan air; kualiti air; produktiviti air bawah tanah; telaga tiub

INTRODUCTION

Groundwater in Malaysia is an important resource that can supplement the increasing demand of fresh water for various uses (Mohammed et al. 2009). Although the groundwater has been used for many centuries the usage is limited to the shallow unconfined aquifers using dug wells (Ang 1994). In Malaysia, deep tubewells in coarse sand aquifers have started to be developed in the past 30 years for water supply of coastal towns such as Kota Bharu (Sofner 1989).

The quality of the water is often described by the mineral composition, turbidity, color, taste and odor. Iron and manganese, which are usually present in groundwater as divalent ions (Fe^{2+} and Mn^{2+}) are considered as contaminants mainly because of their organoleptic properties (Ellis et al. 2000). Other contaminants in groundwater may include ammonium, arsenic and phosphate. Fortunately the method of treatment for the removal of these contaminants is available (Katsoyiannis et al. 2008).

Recent development of well drilling in Malaysia is driven by the expansion of industries and population growth in remote areas where connection to the main water supply is not available. Alternatively the groundwater becomes an attractive source of water supply. However many of the factories are located in areas that are underlain by metasedimentary rocks where the porosity and permeability is known to be very low (Geological Survey

Department of Malaysia 1992). Fractured rocks, however was reported to have relatively high hydraulic conductivity of between 0.001 to 10 m/day (Bouwer 1979).

Metasedimentary rock in Malaysia has a wide distribution covering almost 65% of the entire country particularly in undulating and hilly topography areas. The search for groundwater in these areas began in mid eighties after the country was experiencing a long dry period sometimes in early eighties (Geological Survey Department of Malaysia 1987). This paper presents the findings of a study on the availability of groundwater in fractured metasedimentary rocks in Malaysia for water supply to remote communities and industries. The study also examined the quality of the groundwater and the industries that are using the water.

METHOD OF STUDY

The method of study involves both observation of drilling operations and analysis of well logs. The observation was conducted in 2008 while the logs were from drilling records between 1992 and 2008. The wells were drilled by a private driller in the states of Melaka, Negeri Sembilan, Selangor and Kedah. Sixty six tubewells, drilled for industrial and drinking water supply in the West Coast of Peninsular Malaysia were examined in this study (Figure 1). The tubewells typically penetrated though the soil or loose quaternary alluvium, and weathered metasedimentary rock until reaching the fracture zones that produce water in the hard unweathered part of the rock. The upper parts of the wells were provided with steel casings of 355 mm diameter while in the lower part when the wells reached the medium and hard rock, PVC pipe casings of 200 mm were used. The drilling may reach a maximum depth of around 200 m unless a fractured zone that produces sufficient water with a minimum production rate of 100 m^3/day was encountered.

Three types of drilling methods were used namely Rotary Drilling with water circulation, Air Percussion Rotary and Air-Foam Rotary. The drilling by water circulation using mud of bentonite or polimer was used for the upper soft residual soil and loose alluvium or weathered bedrock where the size of the well is 350 mm diameter.

Air percussion rotary drilling method was used for drilling in the medium hard of semi-weathered and unweathered section of the rock. Air compressor generating 250 psi was used during drilling to bring the rock chips to the surface of the ground. In this section of the borehole the size is 210 mm in diameter.

Tubewells that met the required discharge rate were developed into production wells. The development was carried out by airlift method throughout the entire length of the borehole by blowing compressed air at two meter intervals from the top of the screen section downward to the bottom of the tubewell, and then upward again to the top of the top screen section. Development operation usually lasted for about 6 hour or until the air-lifted water became clear and sand free.

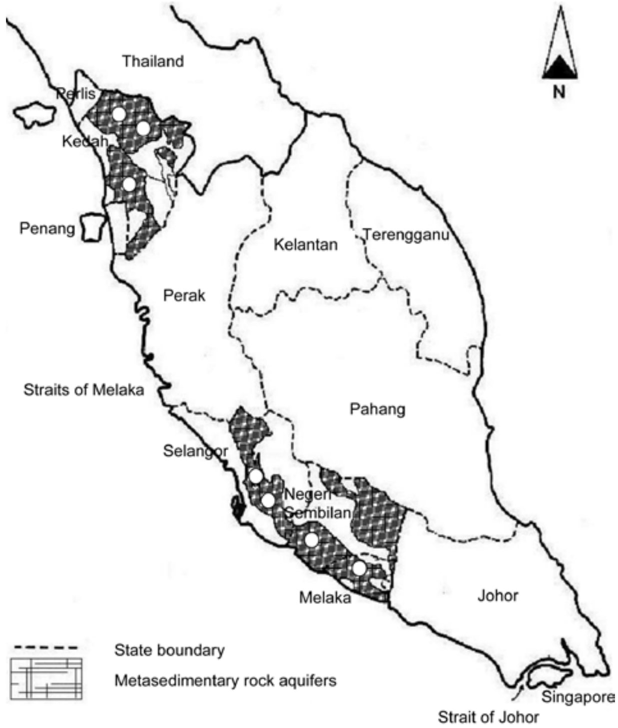

FIGURE 1. Location of wells fields [symbol] in West Coast of Peninsular Malaysia

Pumping test was conducted using a submersible pump installed at about 80 m below the ground level considering the depth of the pump, a safe drawdown at around 40 m was considered appropriate. Both step drawdown and constant discharge rate methods were used to determine the optimum yield of the wells. The discharge rate was determined by measuring the heigth of the water flow over a 90^o V-notch weir and using the following formula:

$$Q = 1.34H^{2.48}.$$

where, Q is the discharge rate, m^3/day and H is the vertical distance from crest of weir to the free water surface, m

Water samples were collected during the pumping tests for water quality analysis according to the Standard Method (APHA 1981). The parameters that were analyzed include pH, major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+), major anions (HCO^-_3, SO^{2-}_4 and Cl^-), conductivity, total dissolved solids, iron and manganese. From the results the hardness of the water was determined.

The characteristics of the developed wells were recorded in terms of their discharge rate, water quality and the intended use. The locations of the wells were also recorded which often limited by the boundary of the land owned by the industry except for the government wells. In fact, the site was located randomly based on the availability of the land space within the boundary of the property that belongs to the particular industry.

RESULTS AND DISCUSSION

Results from the drilling operations are shown in Figure 2, where the depth of the successful wells varies from 70 m to 201 m with an average of 146 m. From the sixty six drilling records examined, fifty seven were successfully developed into production wells with a minimum flow rate of 100 m^3/ day. Thus, the success rate of the drilling operation was 84 percent. The maximum yield obtained from the wells was around 890 m^3/day, and the average from 66 wells was 381 m^3/day. The average drawdown during the pumping test was about 40 to 50 m.

Results of the water quality analysis on total dissolved solids (TDS) are shown in Figure 3. The results indicate that 74% of the wells produced water with total dissolved solids between 101 and 200 mg/L. At this TDS level the water can be classified as fresh water according to Hem (1970) (as cited by Bouwer, 1979). Therefore, the water is suitable for various usage such as agriculture, industry and domestic water supply.

Detail analysis on ions content in water samples from the wells in Selangor, Melaka, Kedah and Negeri Sembilan are presented in bar diagrams as shown in Figure 4. The groundwater from Selangor is found to be of sodium-bicarbonate while the water from Melaka, Kedah and Negeri Sembilan are of calcium-bicarbonate type.

There were minor differences between the four locations in terms of the cations content. Calcium and magnesium were found to be higher in groundwater from Kedah and Melaka. This could probably the result of leaching and weathering of minerals in the rocks such as gypsum, anhydrite, dolomite and aragonite or calcium carbonate which consist of calcium. However, the magnesium seems less soluble compared to minerals that contain calcium which makes in most case calcium is higher than magnesium. The average combined content of calcium and magnesium in groundwater from Melaka and Kedah are 1.86 meq/L and 1.65 meq/L, respectively.

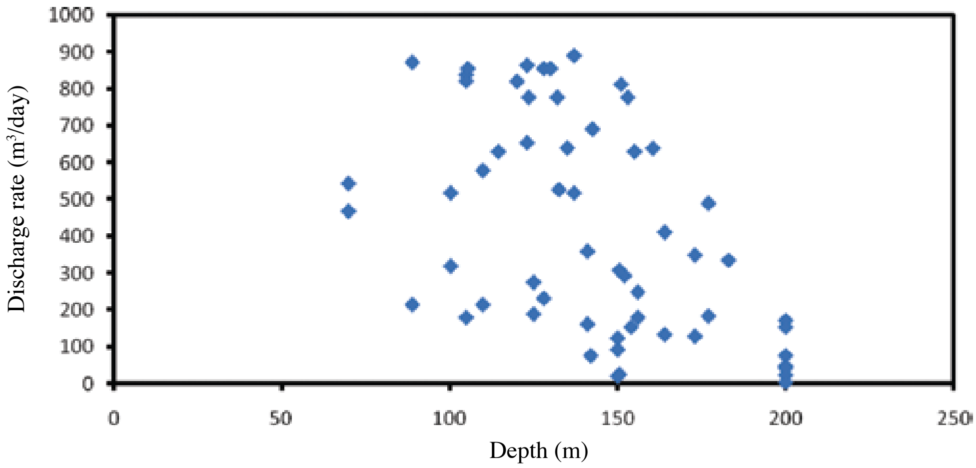

FIGURE 2. Depth of the wells and their optimum yield

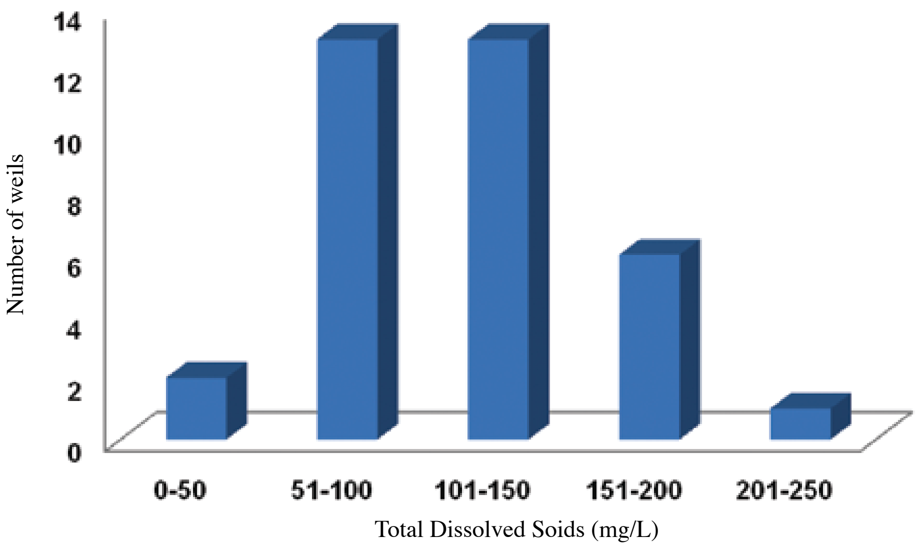

FIGURE 3. Number of wells and the TDS levels (from 34 wells)

(a)

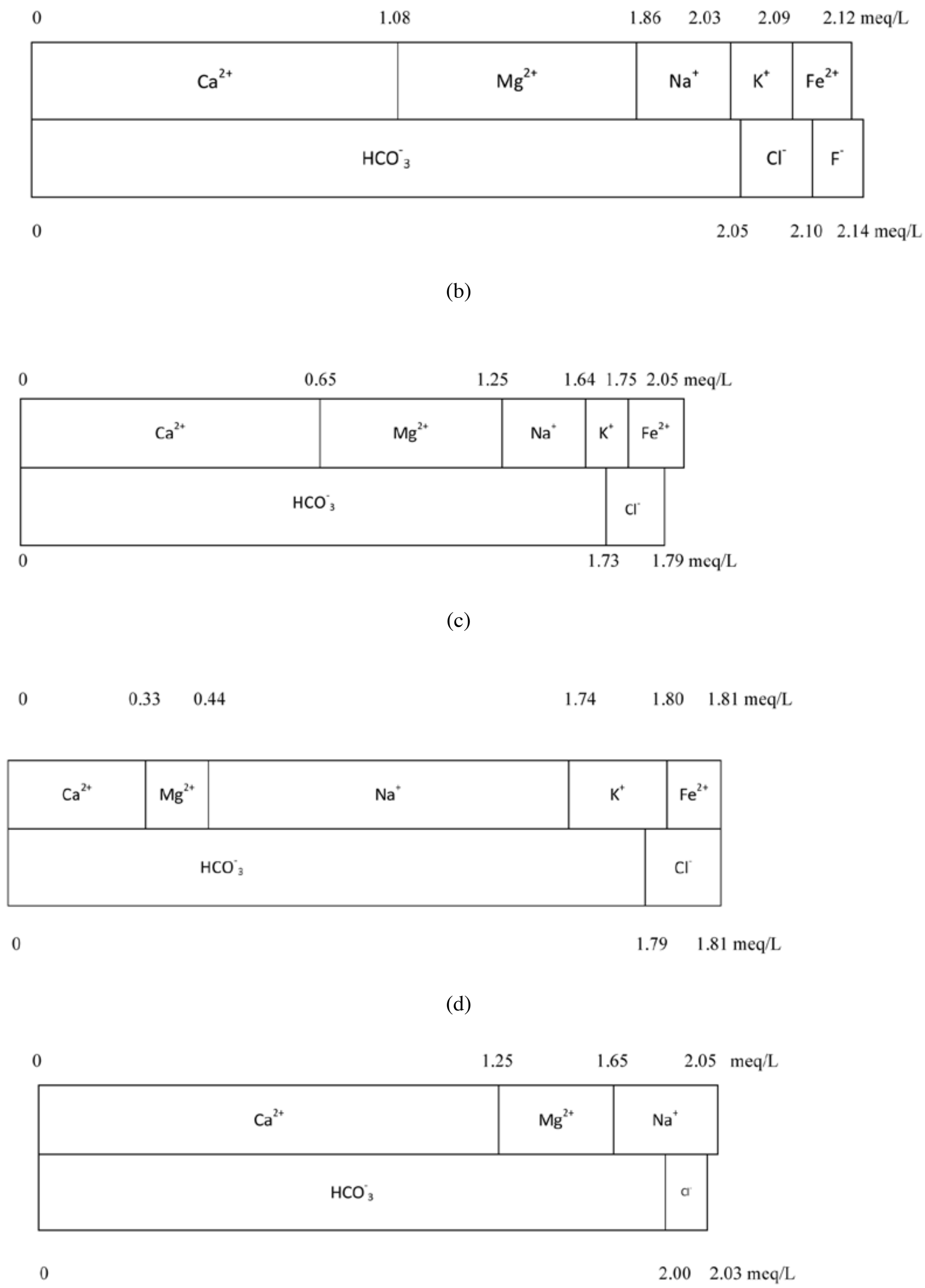

FIGURE 4. Bar diagram of the water in (a) Melaka, (b) Negeri Sembilan, (c) Selangor and (d) Kedah

The Piper Diagram (Figure 5) shows the percentage of major cations and anions in the groundwater from metasedimentary aquifers. The shapes (triangle, cubic, sphere and diamond) represent the states. For examples wells in Melaka which are plotted in triangle show the groundwater contains 51% of Ca^{2+}, 37% of Mg^{2+}, 15% of Na^+, K^+, 2% of Cl^-, 0% and about 98% of HCO_3^-. For the diamond-shaped above the triangles, the group of Ca^{2+} and Mg^{2+} has percentage of about 85%, Na^+ and K^+ about 15%, + Cl^- is 2% and is 98%.

The hardness of water sample from the 22 wells was found to range from 12.64 mg/L to 353 mg/L with an average value of 80.28 mg/L. The average water hardness indicates moderate level of hardness. However, 41% of the wells produced soft water with hardness less than 61 mg/L. Only eleven wells produced hard groundwater with hardness level of around 150 mg/L and one well produced very hard water with hardness level of 337 mg/L.

Results of analysis on iron content are shown in Figure 6. The concentration of total iron varies from undetectable levels to as high as 14.8 mg/L. This may be due to the leaching of minerals like pyrite (FeS_2) which is common in metasedimentary rock (Hall et al. 1987). The average iron content from 36 wells is 2.39 mg/L. The water in Negeri Sembilan generally produced water that contains high iron levels. Figure 6 shows the distribution of the iron content in the water from different wells. This does not show any correlation with the depth of the wells where R^2 is 0.014. However, about 19% of the wells contain iron less than the WHO drinking water standard of 0.3 mg/L (Peavy et al. 1985). This shows that most of the wells in fractured metasedimentary produce water that require iron removal.

The method of treatment currently used by the industries is adsorption by granular activated carbon or impregnated sand materials. The adsorption capacity of activated carbon for Fe(II) and Mn(II) were 3.6010 and 2.5451 mg/g, respectively (Jusoh et al. 2005).

The usage of the groundwater from the successfully developed wells is shown in Table 1. The locations of the industries are located all over the country. The presence of the groundwater in fractured metasedimentary rocks has fulfilled the demand of water by various industries and rural communities.

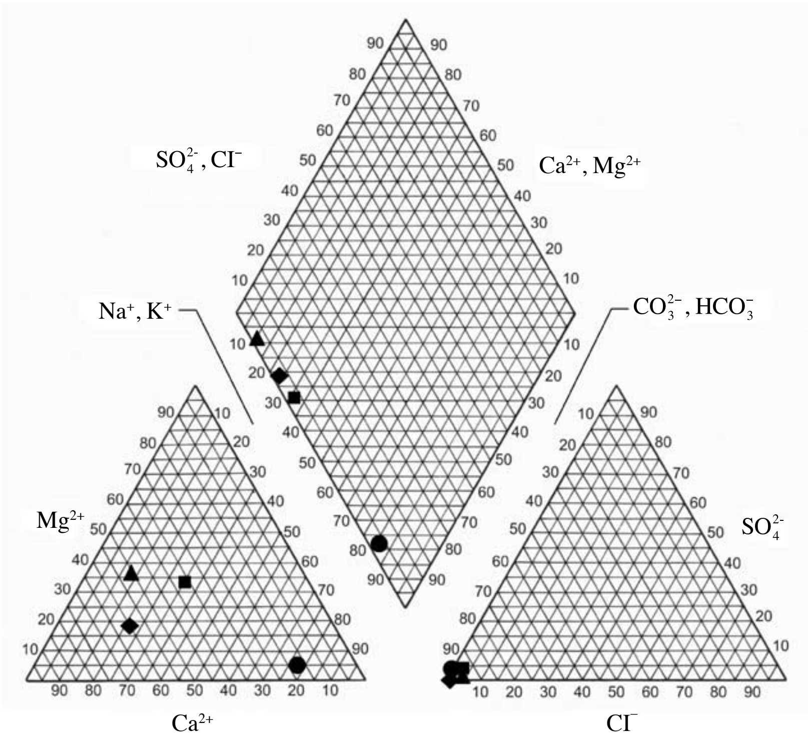

FIGURE 5. Piper diagram ▲ Melaka, ■ Negeri Sembilan, ● Selangor and ◆ Kedah

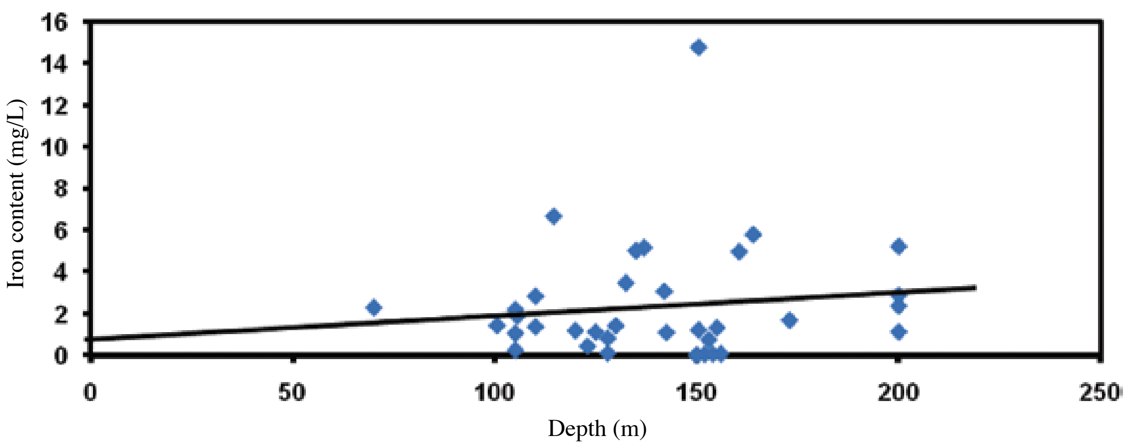

FIGURE 6. Concentration of total iron in water samples from 36 wells

TABLE 1. Number of wells from metasedimentary rocks and their use

Usage	Number of wells
Agriculture (Rubber processing and farm)	11
Drinking (Domestic, school and mineral water)	11
Construction industry (Quary and brick factory)	26
Manufacturing (Paper, textile and ceramic)	7
Research	2
Total	57

One of the advantages of using groundwater is that it is available at the site without the need of transporting and extensive piping system. Currently, the highest usage of groundwater is in construction industry followed by drinking water supply and agriculture. Examples of manufacturing sector that consume high quantity of water include paper and textile industries. Furthermore the groundwater is also used for domestic purposes and mineral water bottling. In addition, latex processing plant and golf course are another consumer of groundwater.

CONCLUSION

Groundwater in interconnected fractured metasedimentary rocks in Malaysia has a steady flow that sustains production during the pumping test. The depth of the wells involved in the study varies from 70 to 201 m with an average of 146 m deep. The average yield from the wells is 381 m^3/day.

The water is generally fresh water with TDS levels between 100 and 150 mg/L. The hardness of the water is also low of around 60 mg/L or less. Only about 9% of the wells produce hard water with hardness levels above 120 mg/L.

The average iron content of the groundwater is 2.39 mg/L. Only 19% of the wells contain iron lower than the WHO drinking water standard of 0.3 mg/L. Treatment for iron removal is therefore necessary prior to usage.

The availability of groundwater in fractured metasedimentary rocks has supported the development of industries and domestic water supply in remote areas; such industries include manufacturing, agriculture and mineral water bottling. Finally, it can be concluded that the availability groundwater in fractured metasedimentary rocks has benefited the development of industries in the west coast of Peninsular Malaysia. This resource has potential to be further exploited for water supply particularly to remote areas.

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