ISSN: 0128-7680
Pertanika J. Sci. & Technol. **17 (1)**: 33 – 42 (2009)

Evaluation of Yield and Groundwater Quality for Selected Wells in Malaysia

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ABSTRACT

In Malaysia, the use of groundwater can help to meet the increasing water demand. The utilization of the aquifers is currently contributing in water supplies, particularly for the northern states. In this study, quantitative and qualitative assessments were carried out for the groundwater exploitation in the states of Kelantan, Melaka, Terengganu and Perak. The relevant data was acquired from the Department of Mineral and Geoscience, Malaysia. The quantitative assessment mainly included the determination of the use to yield ratio (UTY). The formula was proposed to determine the UTY ratio for aquifers in Malaysia. The proposed formula was applied to determine the maximum UTY ratios for the aquifers located in the states of Kelantan, Melaka, and Terengganu, and were found to be 4.2, 5.2 and 0.6, respectively. This indicated that exploitation of groundwater was beyond the safe limit in the states of Kelantan and Melaka. The qualitative assessment showed that the groundwater is slightly acidic. In addition, the concentrations of iron and manganese were found to be higher than the allowable limits, but the chloride concentration was found within the allowable limit.

Keywords: Quantitative, qualitative, assessment, groundwater, aquifers, tropical region

ABBREVIATIONS

ASR: Aquifer Storage Recovery
UTY: Use to Yield Ratio
USEPA: United States Environmental Protection Agency

INTRODUCTION

Groundwater is an important component of the natural water resources system and human beings have utilized it ever since ancient days. The development in drilling and pumping technologies make the usage of groundwater easier, and this enables human beings to use the storage of very deep aquifers. Groundwater may be cheaper than the treated surface water. Beside the advantage of low turbidity, it also contains nutrients which are good for health. The utilization of groundwater can help to solve the water shortage in areas where surface water is limited. Similarly, it can be used to supplement the surface water supplies. However, pollution may restrict and affect the exploitation of groundwater for potable uses.

Malaysia is a tropical country with an abundant amount of surface water. Most of the states in Malaysia are using surface water to meet the various water demands. Due to the global weather changes, the increasing demand and severe pollution of the surface water

Received: 21 August 2007
Accepted: 17 October 2008
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groundwater become an important source for water supply. In Malaysia, the groundwater storage is estimated to be 5000 billions m^3 and only less than 2% of the present storage has been used (Azuhan, 1999). Generally, the lack of extensive exploitation for groundwater in Malaysia can be related to:

1. the failure to recognise the vast potentials of the groundwater resources
2. the misconception that groundwater exploitation is not sustainable
3. the lack of full assessment of the groundwater resources

The use of groundwater for domestic purposes is mainly confined to rural areas, where there is no piped water supply. However, groundwater is being significantly utilised for public water supply in Kelantan and Perlis. The other states, which supplement the water supply systems groundwater, are Terengganu, Pahang, Sarawak and Sabah. In Kelantan, groundwater plays a very important role in the public water supply system. About 70% of the total water supply in the state is derived from groundwater, primarily in the Kota Bharu areas. The rural population is dependent very much on groundwater for their daily requirements, and they obtain it from the shallow dug wells. In Malaysia and during the 1998 dry spell, groundwater has provided relief for the people, especially in Selangor and Sarawak. So, there is a great potential in the use groundwater supplies to meet the increasing demand, and for this reason, a special emphasis must be given to sustainable development of groundwater.

In this study, the exploitation of groundwater from aquifers located in the four states in Malaysia was assessed using the proposed formula, and a qualitative assessment was conducted in order to evaluate the quality of the groundwater.

LITERATURE REVIEW

Groundwater is a very important component of water resources in nature. It is the main source of water supplies in many countries, and this justifies the efforts given by the researchers to improve the studies conducted on groundwater. In this study, relevant selected studies were also reviewed.

Hutchison and Hibbs (2008) analysed groundwater budget in arid basins and substantially aided by integrating the use of numerical models and environmental isotopes. Strassberg *et al.* (2007) developed and applied a data model, for spatial and temporal groundwater information, within a geographical information system (GIS). Wehrmann *et al.* (2003) used the GIS technology to determine the township use to yield ratios for the three aquifer types (sand-gravel, shallow bedrock and deep bedrock). For this purpose, they suggested the following equation to determine the ratio:

$$Y_T = a_1 y_1 + a_2 y_2 + \ldots + a_n y_n \tag{1}$$

where,

Y_T = Area-weighted total township potential aquifer yield, gallon per day (gpd)

a_n = Area within the township containing a particular potential aquifer yield, square miles (mi^2)

y_n = Potential aquifer yield of selected polygon, gallons per day per square mile (gpd/mi^2)

Bisson and Lehr (2004) proposed modern technologies for groundwater exploration, which were adapted from the oil and mineral exploration industries for evaluating, developing and managing previously undiscovered massive sustainable groundwater. In addition, the remote sensing technique was also used for the groundwater exploration in Egypt by El-Baz *et al.* (2004). Lubczynski and Roy (2004) applied the nuclear magnetic resonance (NMR) in the determination of the subsurface free water content and hydraulic properties of the media.

Burbeg (2008) conducted a 62 day controlled aquifer test, in thick alluvial deposits at Mesquite, Nevada in USA, using a high-precision global positioning system (GPS) network to evaluate the aquifer systems during an aquifer test.

Rutledqe (2007) proposed a mathematical method to improve the reliability of recharge estimates of the groundwater. Rainfall is an important source of groundwater recharging. Fleckenstien *et al.* (2006) studied the impact of the low river flow on aquifer recharge. Cui and Shao (2005) studied the role of ground water in the ecosystems, including the effect of water condensation and water table depth on the growth of plants and the degree of soil salinity.

USEPA (1994) outlined the guidelines for delineating the captured zone. This could help to identify the wellhead protection areas, with designated land uses, to reduce the potential for groundwater contamination. The delineation of the captured zone could be simple and just a fixed radius from the well or complex, which needed hydrogeologic modelling. The captured zone or the source of waters to a well or well field must be identified in order to evaluate the quality of groundwater which would be obtained from it. The evaluation would reveal if any contamination occurred.

Fass *et al.* (2007) conducted a study on the unconfined coastal aquifer of the tropical Burdekin River delta, located in the north-eastern of Australia. They found that groundwater, in this areas, was high in chloride concentrations up to almost three times that of the sea water; this occurred up to 15 km of the present coastline. They attributed this to the transpiration by mangrove vegetation during the periods of high sea level. They found that Radiogenic (14C) carbon isotope analyses indicated that groundwater, with chloride concentrations between 15,000 and 35,000 mg/L, was mostly between 4000 and 6000 years old, at which time, the sea level was 2 to 3 m higher than the present.

Marin (2002) conducted an appraisal study on groundwater exploitation in Mexico and he reported that 1/3 of the total water use for agriculture, drinking water supplies and industrial purposes came from the ground water. In Mexico, about 70% of the drinking water supplies came from groundwater, and 75 millions out of 100 millions of the population were dependent mainly on groundwater as a source of water supply. In agriculture, groundwater used to irrigate 2 million hectares of land. The main problems of groundwater are overexploitation, contamination and slatwater intrusion. About 8000 km has significant slatwater intrusion problems in nine aquifers.

STUDIED AQUIFERS AND METHODOLOGY

In Malaysia, groundwater exploitation can help to meet parts of the increasing demand. Currently, groundwater is being used to meet various types of demand *(Fig. 1)*. The integration of surface water and groundwater usage are needed to ensure a sustainable utilization of water resources. In this study, the exploitation of groundwater, from four states in Malaysia, was evaluated. The related data was acquired from the Department of Mineral and Geosciences, Malaysia and this Department is responsible for monitoring and the management of groundwater in Malaysia.

The characteristics of aquifers in the four states in Malaysia, namely Kelantan, Melaka, Terengganu and Perak, were also presented. The aquifer in Kota Bharu, Kelantan is defined by alluvium quaternary and it is based on granite rock or metamorphic rock. The thickness

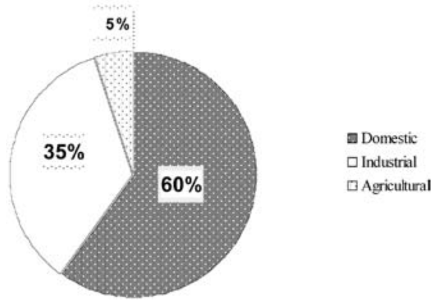

Fig. 1: Various demands for the exploited groundwater in Peninsular Malaysia

of the alluvium quaternary has several meters near the foot of a hill and more than 150 m close to the sea. The alluvium layer consists of clay, sand, silt and gravel. There are two systems of aquifer - these are shallow and deep aquifers. The shallow aquifer includes all aquifers with a thickness of lesser than 15 m and it is categorized as an unconfined aquifer and semi-confined aquifer. The deep aquifers include all the aquifers with a thickness of more than 15 m. This can be found in a semi-confined aquifer or confined aquifer. The shallow aquifer system consists of water, except for the groundwater near to the sea. As for the deep aquifer, salty water can be found near the seaside, and at a depth of 30 m to 50 m, with a distance of about 5 km from the sea.

The aquifers in Melaka are metamorphic rock, igneous rock, and consolidated alluvium layer, which is built of clay or sand at the seaside area. The main limestone is found forward the northwest, at the centre and east Tengah district and the minor limestones found in various directions in metamorphic rock or granite. The wells were constructed either in alluvium or in rock aquifers. The thickness of the alluvium layer is between 2.25 m – 19.5 m.

The aquifers in Terengganu are alluvium quaternary aquifer with silt and soft sand, with a base rock at depth of about 28 m. Due to the fact that the silt layer is thin and less than 5 m, the aquifer is mainly categorized as semi-confined aquifer. The aquifer in Perak is categorized by granite and metamorphic rocks, which are represented by limestone, shale, sandstone and tuff layers.

The methodology used was based on computing the use so as to yield the ratio (UTY) for selected aquifers in the studied area. In addition, the quality of the groundwater, from each aquifer, was assessed based on the standards set for drinking water. *Fig. 2* is used to determine the potential yield of each aquifer, while the data related to the pumping from the wells were used to compute the UTY ratio. In the present study, the following formula was proposed to compute the UTY ratio for the Malaysian aquifers:

$$UTY = \frac{\sum_{i=1}^{i=n} y_{wi}}{(y_m)(n)} \tag{2}$$

where

y_w is the actual discharge pumped from a well i in m^3/ hr, y_m is the potential yield in m^3/hr/well from a particular aquifer, and n is the number of wells in the aquifer.

The high UTY was found to be almost 1, suggesting a groundwater exploitation problem in the area.

Fig. 2: Yield of the aquifers in Peninsular Malaysia
(*Source*: Department of Minerals and Geoscience, Malaysia)

The assessment of groundwater quality was carried out based on the available data; few parameters were studied and these parameters included iron, pH, chloride, and manganese. The concentrations of these parameters in the groundwater were compared with the guidelines for drinking water. The methodology would help to conduct the qualitative and quantitative assessments to identify the groundwater exploitation in the studied area. At the same time, the acquired data was subjected to the processing and cataloging so that it could be more useful in the assessment process. *Fig. 3* shows a schematic flowchart for the methodology used.

RESULTS AND DISCUSSION

Quantitative Analysis

In 1995, about 98000 m^3/ day of groundwater was pumped from more than 60 wells to meet the demand of about 30% of the population of Kelantan. Considering this fact, nine more well fields will need to be constructed in order to meet the increasing demand by 2010. For the state of Melaka, the groundwater supply from the district plain can produce 1256 m^3/day to meet the demand of about 9000 people, and it was developed to produce 1430 m^3/day to

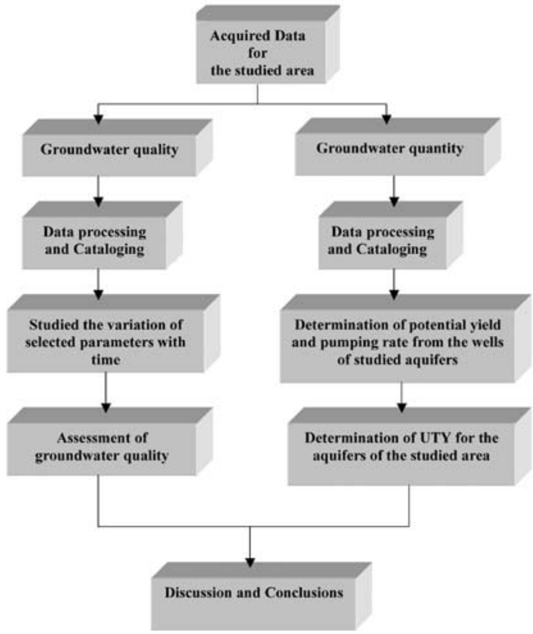

Fig. 3: Schematic flowchart of the methodology

meet the demand of 10210 persons. The discharge of salty groundwater, which is used for non-potable uses, is not included in the quantitative analysis. For the state of Terengganu, groundwater is being used in the Marang district, and the pumping is estimated to be 2200 m^3/day, and this meets the demand of 2200 people. Pumping from various well fields ranges form 160 m^3/ hr to 8 m^3/ hr. As for the state of Perak, groundwater is mainly used to meet the demand of the villages located in the rural areas. The pumping of groundwater is 180 m^3/ day, and this amount is used to meet the demand of 1278 people. *Fig. 2* shows the location of the aquifers with the potential yields. For industrial purposes, groundwater is utilized for cleaning, washing and cooling. Major areas such as Shah Alam and Bukit Rajah in Selangor use groundwater substantially for their operations. The utilization of groundwater for agricultural purposes is not very well developed, and this is normally confined to isolated agricultural areas or other areas outside many irrigation schemes.

Nevertheless, groundwater is being extensively used by Agricultural Commodities Centre in Terengganu and in aquaculture farm in Pekan, in Pahang. *Fig. 4* shows the daily consumption of the groundwater, distributed among various uses, while *Fig. 5* exhibits the number of wells allocated for various uses. *Fig. 6* shows the average yield for various wells in Peninsular Malaysia.

Safe yield is defined as a long-term balance between the natural and artificial recharge of an aquifer and the discharge from it by pumping. When more water is discharged than is recharged, the aquifer is described as being out-of-safe yield. The mining of groundwater occurred when there is a significant drop in the groundwater level of the aquifer. Safe yield can be achieved by a combination of methods. Water conservation will reduce the demand, and stormwater storage facilities can help in recharging the aquifers, since the average annual rainfall in Malaysia is 2500 mm. Achieving safe yield is important primarily because a continuous reduction in the groundwater level in an aquifer will make the supply of water to

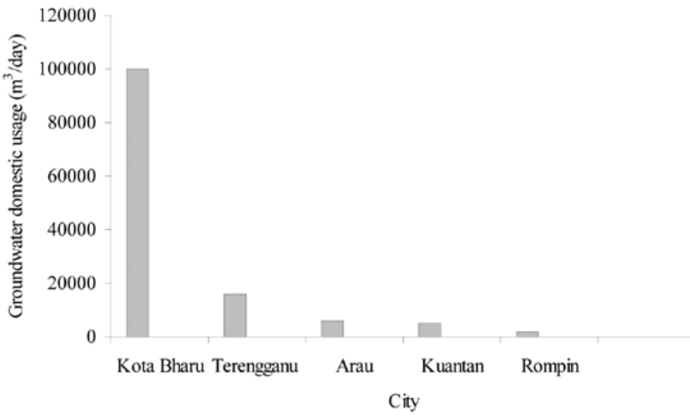

Fig. 4: Daily consumption of groundwater for domestic uses in selected cities in Malaysia

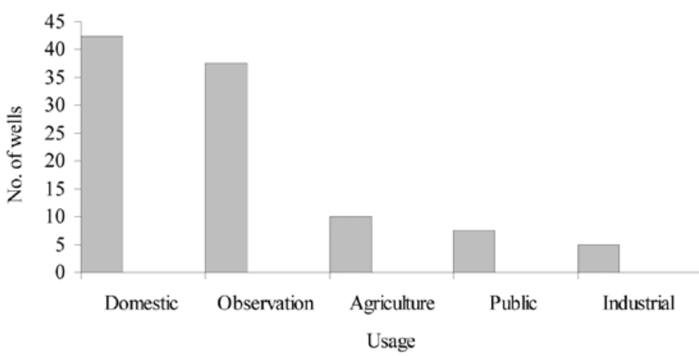

Fig. 5: Number of wells distributed based on the usage of groundwater

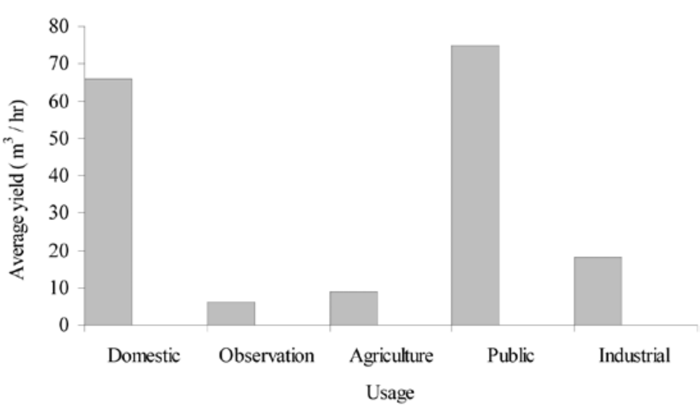

Fig. 6: Average well yield for various uses

be uneconomical. In addition, the drop in the groundwater level will damage the structure of the aquifer material. Wehrmann *et al.* (2003) made a comparison of the groundwater use to the aquifer yield, and as a result, they proposed a ratio called use-to-yield (UTY) and its values ranged from 0.5 to 0.9 for sand and gravel aquifers, but they also found that UTY was more than 0.9 for some areas within Illinois, USA. At the same time, they discovered that the estimated potential yield of deep bedrock aquifer system was 246025 m^3/ day.

In this study, Equation (2) is used to compute the UTY ratio to assess the pumping from the wells for the studied aquifers in Malaysia. The UTY ratios for the places utilizing the groundwater are shown in Table 1. The UTY ratio greater than 0.9 is not preferable because the high ratio suggests the existence or impendence of problems related to groundwater availability in a particular area. Wehrmann *et al.* (2003) proposed the UTY ratio of 0.9 for any critical case. The UTY ratios are acceptable for the wells in Terengganu. Lowy and Anderson (2006) proposed storage recovery (ASR) to optimize the available water resources and reduce adverse effects of pumping on the aquifer.

TABLE 1
Values of the use to yield ratios for the groundwater wells in Malaysia

State	Maximum UTY ratio	Minimum UTY ratio
Kelantan	4.2	0.51
Melaka	5.2	0.09
Terengganu	0.66	0.04

Qualitative Analysis

From the acquired data, it was found that the quality of the groundwater in some of the wells contained a high concentration of iron (up to 6 mg/l), while the recommended value is 0.3 mg/l. It is recommended to use the water for non-potable purposes. *Fig. 7* shows the variation of pH for the groundwater pumped from the wells located at Kelantan, Melaka and Terengganu. The low pH indicates the acidity of the groundwater. The recommended pH value for drinking water is 6.5. Guan *et al.* (2003) proposed the concept of critical pH which could assist in the design of geologic barriers to prevent viral contamination in groundwater. A critical pH value is 0.5 unit, which is below the highest isoelectric point of the virus and porous medium. The proposal of Guan *et al.* (2003) was based on the experimental and field data.

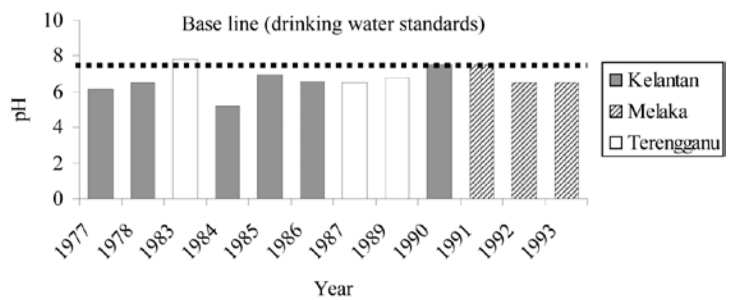

Fig. 7: Variations in the pH of the groundwater

The chloride content in groundwater is less than the recommended value for the drinking water, which is 250 mg/l, as shown in *Fig. 8*. Similarly, it is much lesser than the chloride concentration in groundwater of other areas in the Asia Pacific regions such as Northeast costal aquifers of Australia (chloride concentrations range from 15,000 to 35,000 mg/l), as reported by Fass *et al.* (2007).

The manganese concentration in the ground water is higher than the acceptable limits for drinking water, which is 0.05 mg/l (*Fig. 9*). Definitely, treatment is required for potable uses, although the concentration of the manganese is not very high (0.3 mg/l and less). Moreover, salty groundwater was found from the wells located near the coastal areas. Usually, the groundwater wells which are located near the coastal areas are affected by the salt intrusion phenomenon. Higher pumping rates will make groundwater of higher density (salt water) to be discharged from a well. So, high pumping rates and continuous pumping from the wells near the coastal areas will lead to saltwater intrusion and groundwater contamination unless precautionary measures are taken. Usually, the concentration of dissolved solids, in the groundwater, is high because it may pass through layers containing solvable materials. Wehrmann et al. (2003) found that the groundwater for the areas in Illinois contained more than 2500 mg/l of dissolved solids.

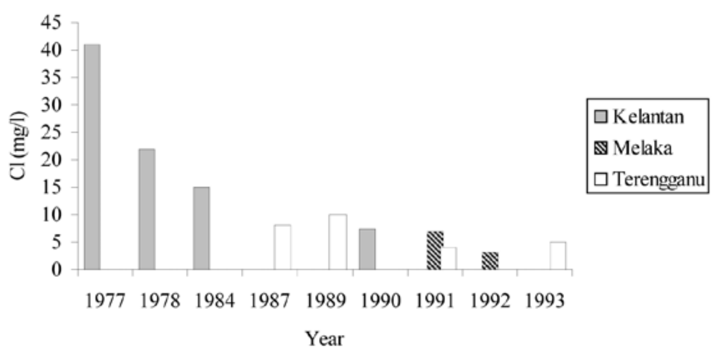

Fig. 8: Variations in the chloride concentrations in groundwater

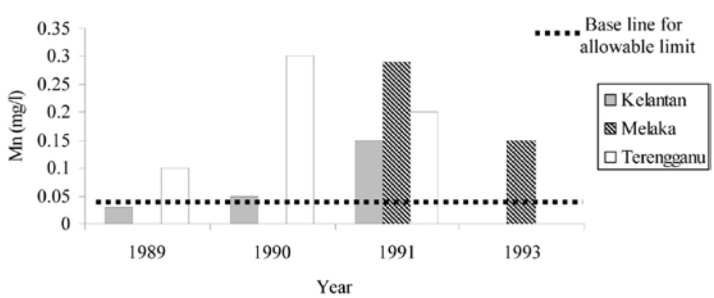

Fig. 9: Variations of manganese concentrations in groundwater

CONCLUSIONS

Although Malaysia is blessed with abundant of surface water, due to its high annual rainfall (about 2500 mm), the country still experiences increasing water demand. Many states in Malaysia use groundwater as a supplementary source to surface water to meet the demand for water supply. In the state of Kelantan, about 70% of the total domestic water demand is met using groundwater. Meanwhile, Melaka and Terengganu are also using groundwater to meet parts of the demand in the two states. The maximum use to yield the ratios (UTY) for the wells under use in the state of Kelantan was found to be 4.2, while the minimum is 0.51. This is an indication that the concept of safe yield and sustainability has not been considered in the utilization of the aquifers in the areas. In the state of Melaka, the UTY is also high, while this is rather low in Terengganu, indicating that the aquifer is under safe yield. The quality of groundwater may determine the type of usage (potable or non-potable). According to the acquired data, groundwater needs some kind of treatment in case that it is planned to be used for domestic purposes.

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