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SHORT COMMUNICATION

INTEGRATED RAINWATER HARVESTING (RWH) AND GROUNDWATER SYSTEM FOR DOMESTIC WATER SUPPLY

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ABSTRACT

The motivation of this study was minimizing usage of billing water via adopting integrated rooftop rainwater harvesting (RWH) and groundwater at Madrasah Tahfiz Darul Hikmah in Parit Kaspan, Parit Raja, Johor. Groundwater exploration using electrical resistivity method was conducted. Based on the 2-dimensional resistivity tomography result, the position of shallow tube well was pointed based on low resistivity and low chargeability. Tube well at 2-inch diameter was constructed at 20-m depth. Preliminary analysis was conducted, and a few contaminants were detected in groundwater and rainwater, making it unsafe for domestic purposes and need to be treated to an acceptable level. Multiple treatments such as sedimentation, sand and membrane filtrations, and dilution were applied to improve the groundwater quality. Few parameters were selected and analysed namely pH, turbidity, total dissolved solids (TDS) and heavy metals (i.e., Fe, Mn, Zn and Cu). Overall, the blended groundwater and rainwater water treatments efficiently reduced the concentration of pollutants in the filtered water to a compliance of recommended raw water quality standard.

KEYWORDS

Rainwater harvesting, groundwater, resistivity, filtration, domestic water supply, alternative water resources

1. INTRODUCTION

The demand for clean water resources in Malaysia is increasing, where the daily water consumption per capita of Malaysia increased by about 7.6 liters a year (Law and Bustami, 2013, Ahmed et al., 2014, Oh et al., 2018). The most significant increment is seen in domestic water demand, which is approximately 8.8 billion m^3 (Ahmed et al., 2014). Increased in water consumption does not in-lined with the increases in water reserves. Since 2005, Malaysia's water reserves per capita per day have declined by 5.8 liters a year. Practicing RWH and groundwater extraction are among the solutions in addressing problems in areas with inadequate water supply. Both of these sources are said to have excellent potential as alternatives water supply in Malaysia. However, the main issue of using rainwater harvesting is insufficient quantity due to inconsistent precipitation period. Meanwhile for groundwater usage, the limitation is due to the quality, i.e. higher concentration of dissolved solids. Total dissolved solids (TDS) consist mainly of carbonates, bicarbonates, chlorides, sulfates, phosphates, nitrates, calcium, magnesium, sodium, potassium, iron, manganese, and a few others. The TDS, however, do not include gases, colloids, or sediment. TDS in natural waters ranged between less than 10 mg/L for rainwater, up to more than 35,000 mg/L for sea water. Thus, to integrate these water sources, rainwater and groundwater, could be the resolution for the aforementioned problem.

Many treatment methods can be used to improve groundwater and rainwater quality such as aeration, filtration, nano-filtration, membrane technology and chlorination (Weight, 2008, David et al., 2013). However, moderate treatment should be selected if the quality of the extracted water is adequate for usage (Musa et al., 2015). Of all the methods, filtration is one of the most effective and economical methods used to improve water quality (Musa et al., 2013). Filtration is used to improve water quality, turbidity, taste, and water composition (Muhammad et al., 1996). Previous studies revealed that there were materials such as pebbles, sand, clay, aggregates and ceramics that can be used as part of the medium in water filter in removing suspended solids (Rahmat et al., 2018). On the other hands, another widely used technique is aeration. This technique is widely used in removing dissolved gases and oxidizing dissolved metals such as iron (Bruins et al., 2015). Various types of aeration devices have been used such as diffused aeration, aeration spray and waterfall ventilation. In Netherlands, groundwater treatment usually consists of aeration, with subsequent sand filtration without the use of chemical oxidants such as chlorine (Gude et al., 2016).

Preliminary study was carried out at the Madrasah Tahfiz Darul Hikmah, Parit Raja to integrate the groundwater and rainwater harvesting. Although RWH system received a lot of responses, its implementation was limited due to a number of weaknesses such as inconsistent rainfall and associated costs. Whereas the extraction of groundwater indicates the exceed limit of TDS from the recommended raw water quality standard (MOH, 2004). Therefore, a system that integrates RWH and groundwater extraction has been developed as water supply to this Madrasah. Also, a low cost and easy-maintained water treatment system was introduced. This system involved the process of sedimentation, sand and membrane filtrations, and dilution before water is used.

2. MATERIAL AND METHODS

Madrasah Tahfiz Darul Hikmah is located at Parit Kaspan, Sri Gading, Batu Pahat, Johor (refer Figure 1). This study location is surrounded by palm oil plantation and residential area. Based on geological map from Department of Mineral and Geoscience Malaysia, as shown in Figure 1, the study area is located on Quaternary Period which consists of unconsolidated deposits from marine clay and silt. Generally, the area showed characteristic of soft soils and higher water content due to low static ground water table. The mean daily temperature is about 27°C and the average monthly rainfall data ranged between 75 and 230 mm.

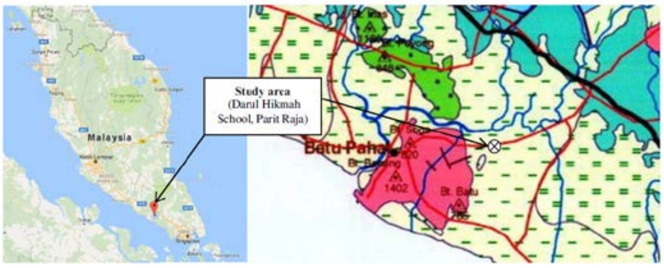

Figure 1: Location and geology of study area

2.1 Groundwater exploration and tube well development

Subsurface exploration method was applied using electrical resistivity tomography to investigate the groundwater potential. Electrical method (electrical resistivity and induced polarization) was performed using ABEM Terrameter LS2 to obtain the electrical resistivity and induced polarization imaging on site. A maximum of 61 electrode pegs were driven into the ground based on four resistivity land cables and 2 m of equal electrode spacing. Total length of 2D resistivity test was 160 m and the survey line-oriented west to east direction as shown in Figure 2. Raw data obtained from the data acquisition was processed using commercialized RES2DINV software to provide an inverse model that approximates the actual subsurface structure. Inversion algorithm of RES2DINV was applied in data processing to obtain 2-D electrical results.

Figure 2: Alignment (west-east) of electrical resistivity performed at Madrasah Darul Hikmah, Kg. Parit Kaspan Parit Raja Batu Pahat, Johor

Results indicated that most of the subsurface resistivity values were below 30 Ω-m as shown in Figure 3. The results from the electrical resistivity imaging showed the subsurface site condition had a relatively low resistivity which indicated higher water and total dissolved contents throughout the study area. This condition corresponded with the lithology of the study area which indicates the presence of low static ground water table. To confirm the interpretation of the result, a drill tube well was performed on the 90th meter of the survey line and the drilled soil was terminated at 30 m depth. The clay layer from top ground surface to 4.5 m followed by sand layer up to 20 m depth. Further increasing depth up to 30 m, mixture of silt and clay was observed.

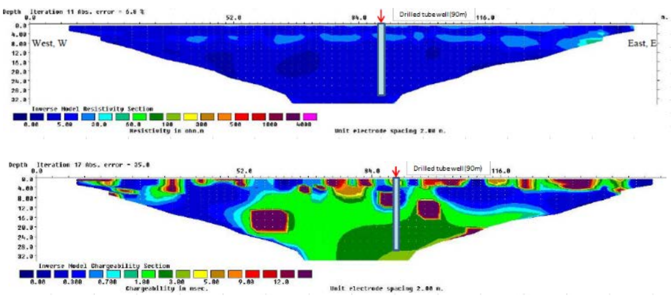

Figure 3: Electrical resistivity and chargeability tomography results

2.2 Design of integrated treatment system

In recent study, rainwater was used in preference to groundwater and the system was equipped with automatic devices. The switching device used floats to automatically detect when sufficient rainwater was available for use in the building. When rainwater levels were low, the device automatically changed back to groundwater and ensured an uninterrupted supply of water to the users. Low-cost treatment system was the main aim of this study. Therefore, both rainwater and groundwater will undergo the same treatment that was designed and installed as shown in Figure 4. For harvested rainwater, the rainwater was collected using the roof catchment and directly transferred to the storage (first) tank (Figure 5). However, to prevent large debris from entering the storage tank, the rainwater was drained through the first flush diverter. Meanwhile, for groundwater, it was extracted using submersible pump from the tube well. The extracted groundwater was pumped and stored in a collection tank. Next, water from the first tank was then pumped and passed through the fiber reinforced plastic (FRP), micro and membrane filters before it is stored in the final storage tank (Figure 6).

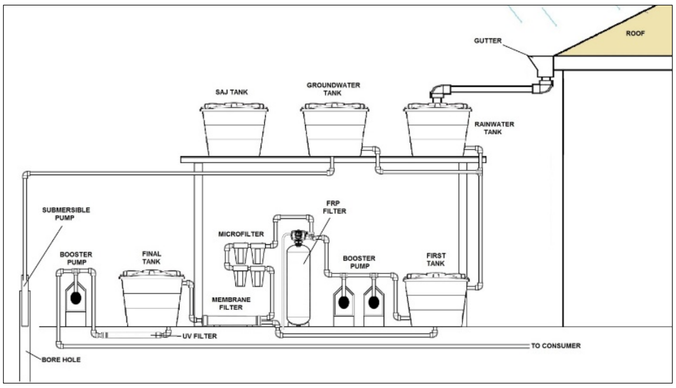

Figure 4: Integrated treatment system schematic diagram

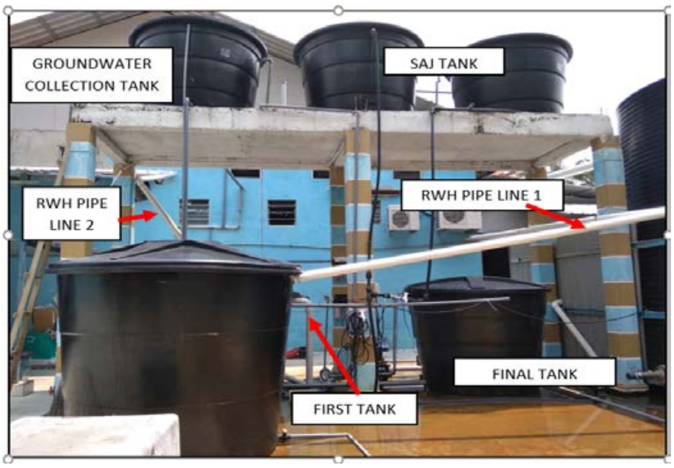

Figure 5: Integrated treatment system at Madrasah Tahfiz Darul Hikmah

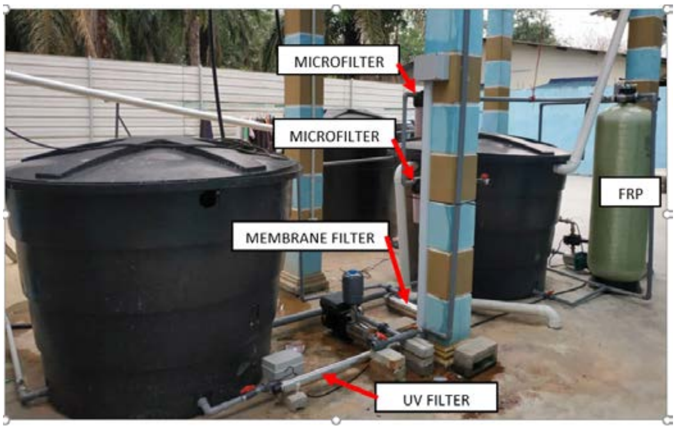

Figure 6: Filtration system for groundwater and rainwater

FRP tank contained silica based catalytic media (DMI-65) granular material which facilitates an oxidation-precipitation-filtration process and was primarily designed to remove iron and manganese in the water. Interaction of DMI-65 with water molecules and ions in solution is initiated through adsorption. Four microfilters with 1-µm pore-size were installed to guarantee the contaminated fluid is filtered through a very small pore-sized membrane to separate microorganisms and suspended particles. In addition, microfilters are relatively inexpensive and easy to maintain. Then membrane filter that was installed to act as a barrier to separate contaminants from water as they remove the particles contamination the water. The water then passes through UV filter before distributed to the users. UV water purification was designed to help in disinfecting bacteria in the blended rainwater and groundwater to ensure the Madrasah's community consume clean and safe water.

3. Results and Discussion

The groundwater and rainwater samples were collected and analysed before and after the treatment process to determine the quality of water and the efficiency of the treatment system. Table 1 shows the groundwater quality at Madrasah before and after treatment. pH values for groundwater and rainwater were complied to Water Quality Standard (MOH, 2004) with mean values of 6.49 and 7.01, respectively. Shallow groundwater samples before treatment exhibited high values of TDS with mean value of 3890 mg/L. Meanwhile for rainwater, the TDS concentration was within the desired standard with value of concentration of 15.6 mg/L before treatment. After filtration, the mixing water between shallow groundwater and rainwater the value of TDS reduced to 911 mg/L reduced to a recommended Raw Water Quality Standard and National Drinking Water Quality Standard (MOH, 2004). Meanwhile, the turbidity of groundwater and rainwater before treatment were high with mean concentration of 54 and 15.6 NTU, respectively. Thus, they could not be consumed due to exceeding the standard limit of National Drinking Water Quality Standard set by (MOH, 2004). After treatment, the results for turbidity decreased to 3.45 NTU and complied to both standards.

Table 1: Groundwater quality at Madrasah Tahfiz Darul Hikmah

Parameters	Before treatment		After treatment (blended)	Raw Water Quality Standard (MOH, 2004)	National Drinking Water Quality Standard (MOH, 2004)
	Ground water	Rain water			
pH	6.49	6.89	7.02	5.5-9.0	6.5-9.0
Temperature, ∘ C	26.98	26.56	26.67	-	-
TDS, mg/l	3890	15.6	911	1500	1000
Turbidity, NTU	54.0	12.53	3.45	1000	5
Iron (Fe), mg/l	0.579	0.016	0.011	1.0	0.3
Manganese (Mn), mg/l	0.2570	0.001	0.125	0.2	0.1
Copper (Cu), mg/l	0.005	0.001	0.002	1.0	1.0
Zinc (Zn), mg/l	0.157	0.028	0.125	3.0	3.0

For heavy metal, the mean concentration values of Fe, Mn, Cu, and Zn of raw groundwater were 0.579 mg/l, 0.2570 mg/l, 0.005 mg/l and 0.157 mg/l, respectively. For rainwater, the concentration values of Fe, Mn, Cu, and Zn were 0.016 mg/l, 0.001 mg/l, 0.001 mg/l and 0.028 mg/l, respectively. All parameters for raw groundwater complied with the requirement of the Recommended Raw Water Quality by Ministry of Health Malaysia (MOH, 2004). Unfortunately, only Cu and Zn complied with the Drinking Water Quality Standard (MOH, 2004). Under natural condition, the dissolve ion in the water is related to the mineral assemblies in rock near the ground surface (Fitts 2012). Mineral texture, porosity, composition, and regional structure of rock also influenced the presence of heavy metals in the groundwater. Meanwhile for rainwater, all parameters within both Recommended Raw Water Quality and Drinking Water Quality Standard (MOH, 2004). After treatment, the concentrations of heavy metals showed improvement with concentrations of 0.011 mg/l, 0.125 mg/l, and 0.125 mg/l, respectively for Fe, Mn, and Zn. Meanwhile, no result was detected for Cu and all parameters are within the standard. It can be concluded that the treatment system installed was able to improve the water quality.

4. Conclusions

The integrated system of rainwater and groundwater was successfully designed and installed in order to bring the water quality of Madrasah to an acceptable level before it can be consumed. Based on the results, full treatment consisting of FRP, micro and membrane filters could remove the concentrations of selected parameters. Overall, this study provides a significant reference for sustainable water management and this approach can be efficiently applied especially for rural areas, where there is no domestic water supply.

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