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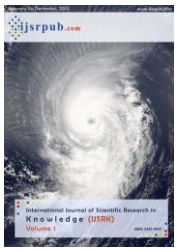

Full Length Research Paper

Alluvial Soil Characteristics and Properties for Riverbank Filtration at Sungai Kerian, Lubuk Buntar, Kedah, Malaysia

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Abstract. Riverbank filtration (RBF) is commonly implemented in many developed countries for more 100 years, but remains new and unexplored in Malaysia. A soil strata ability to drain water at high volume is the essential properties in RBF. Soil characteristics and properties play important roles in determining the suitability of the site for RBF application. This study has been carried out to identify the characteristics and properties of the alluvial soil at the riverbank of Kerian River for different layers at pumping well (PW) and monitoring well (BH1). Particle size distribution and hydraulic conductivity of the soils were obtained from sieve analysis, constant head permeability test and pumping test. From sieve analysis, the top layers to depth 16m of PW and BH1 have high percentage of silt and clay. The soil from depth 16m to 33 for PW and 16m to 30m for BH1 have high percentage of coarse sand and followed by medium sand and fine gravel. Hydraulic conductivity for depth 11 to 30 m were approximately 0.002 m/d to 150.81 m/d and 0.01 m/d to 4.96 m/d based on Hazen and Kozeny-Carman method respectively. Permeability of the soil sample of PW at depth 11 to 16 m, 17 to 23 m, 23 to 29 m and 29 to 33 m were 4.1902 $x10^{-5}$ m/s, 1.2221$x10^{-4}$ m/s, 1.2197$x10^{-4}$ m/s and 1.2555$x10^{-4}$ m/s respectively. For Constant Discharge Test, the hydraulic conductivity and transmissivity were 7.86 m/d and 133.57m^2/d respectively. Overall rate for the production well is 0.737 MLD. Based on the results, this site was found suitable for the RBF water extraction.

Keywords: Riverbank filtration, grain size analysis, hydraulic conductivity, pumping test, permeability

1. INTRODUCTION

Riverbank Filtration (RBF) is a type of filtration processes that functioning by passing water to be purified for commercial uses through banks of a river. Compared to the recent conventional water treatment process, RBF is a natural steps process of water treatment. The common technology applied in this process is by means of employed the aquifer comprising of unconsolidated material deposited by water which typically occurring adjacent to the rivers. For the purposes of this study, the aquifers shall be refers as an alluvial aquifers. Generally, sites with shallow depths are selected because of the significant amount of groundwater that can be extracted (Hiscock and Grischek, 2002). Alluvial aquifers that are hydraulically connected to surface water bodies have been used for water production throughout the world. Hence, study of alluvial aquifers is become a crucial factors to be considered as it will determine the efficiencies of bank filtration.

The detailed profiling of alluvial aquifer is important in selecting suitable well sites and well design. The key factors in selecting and developing of bank filtration sites are the extent of alluvial aquifer and thickness of the aquifer (Shamsudin et al., 2014). The hydrological characteristics such as hydraulic conductivity, transmissivity, storage coefficient, and dispersivity affecting groundwater flow and contaminant transport can be characterized by various laboratory and field tests such as column tracer tests, grain size analyses, pumping tests, slug tests, and field tracer tests (Vandenbohede and Lebbe, 2003). Alluvial aquifers near a river are typically multilayered due to the deposition processes resulting in vertical heterogeneities in hydraulic properties (Kim et al., 2005; Pickens and Grisak, 1981; Mas-Pla et al., 1992; Thorbjarnarson and Mackay, 1997). A suitable site for a RBF would involve sand and gravel aquifers with hydraulic conductivity, $k_f > 10^{-4}$ m/s, a minimal thickness of 5 m and a good hydraulic connection to the adjacent surface water (TZW, 2006a). Studies on the characteristics of a feasible

bank filtration site based on examples from Europe and North America would mention the relevance aquifer thickness, hydraulic conductivity, flow velocity gradient, river discharge, and clogging of the riverbed (Grischek et al., 2002; Ray et al., 2002; Schubert, 2002). The thicknesses of some existing RBF sites in Germany range from 3-5 m at Böckingen, by the Necker River to 40–55 m at Torgau-Ost, by the Elbe River, with hydraulic conductivity ranging between 1 x 10^{-2} and 7.5x10^{-5} m/s (Grischek et al., 2002).

As the study is considered as a new technology in Malaysia, hence continuously study RBF is necessary to adapt with the systems. The identifying of suitable sites via soil characteristics is a key factor in determination of the RBF effectiveness. Ultimately, the purpose of this study is to describe the characteristics of the alluvial soils of the selected site at Kerian River in Lubuk Buntar, Kedah and to evaluate the suitability of the site for RBF application. This paper discusses on soil classification, particle size distribution (PSD), and hydraulic conductivity values of soil samples at the study area that will characterize the potential of RBF.

2. MATERIALS AND METHODS

2.1. Study Area

The study site is located in Lubuk Buntar, Kedah Darul Aman with longitude and latitude of 5° 7'37.60"N, 100°35'42.97"E as shown in Figure 1. The area was near to raw water intake of SADA (Syarikat Air Darul Aman) water treatment plant at Kerian River. Kerian River is the main river at the study area which is the border between Kedah and Perak. The upper stream of Kerian River is Selama and the downstream is Nibong Tebal. Ismail et al. (2014) stated that, the upper stream of Kerian River will face an increase of annual rainfall, while the downstream of the river will face a decrease of annual rainfall from 2011 until 2099. Due to that, the site has experienced flooding for several times. This study site was chosen due to the high water demand in the area and the river has high pollution level. Kerian River has been classified as river class II and III, which indicated that extensive treatment is needed in order to make the water supply using water from this river and RBF is seen as an alternative source with very high potential to be developed as a supplementary source to meet the high public water supply demand. In the stage of the investigation, construction of wells, soil sampling Permeability Test and pumping test were performed to determine the suitability of the RBF and the hydrogeological characteristics of the study area.

2.2. Drilling, Construction of Wells and Soil Sampling

The wells were constructed in September 2013. Figure 2 shows the location of the distance from the PW to the river was 32 m. The distance between BH1 and BH2 was 12 m and the distance between BH1 to the river was 10 m. The drilling of the exploration test well (PW) was carried out using Truck Mounted Rig with mud rotary drilling technique and drilling with 20 inches diameter craw bit. The construction of the exploration alluvium tube well consist of installation of 10 inch stainless steel screen from 24 to 30 m, 1 m sand trap from 30 to 31 m and 10 inch diameter PVC blank from ground level to 24 m followed by 1 meter top of well with steel wellhead protector. The develop 10 inch tube well also consist of 1 installation of 2 inch diameter PVC monitoring well from ground level up to 30 m with screen from 24 to 30 m. Two monitoring wells (BH1 and BH2) were constructed parallel to the PW. Both well were constructed with 30 meters depth using rotary drilling and percussion. During the drilling, samples were collected and described for every meter depth of the borehole and placed in the plastic bag and were then transported to labs. These soil samples were then dried for analysis. This study only focused on the soil samples from PW and BH1 that were collected during the drilling and construction process.

2.3. Sieve analysis of soil samples

Sieve analyses of the soil material were performed to support the results of geological bore logs and also to determine the percentage of different grain sizes contained from the wells. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, while the hydrometer method is used to determine the distribution of the finer particles. This test was conducted for the soil samples from PW and BH1. This analysis was performed based on British Standard 1377: Part 2:1990. The initial mass of the soil in the container was measured and then it was soaked in distilled water for 24 hours. After that, the soil was washed using 63 μm sieve size until the water was clear. The remaining soil on that sieve was dried in the oven for 24 hours. The dried soil was weighed again and started with sieve analysis. The sieves were fixed in the order of 14 mm, 10 mm, 6.3 mm, 5.0 mm, 3.35 mm, 2.0 mm, 1.18 mm, 600 μm, 425 μm, 300 μm, 212 μm, 150 μm and 63 μm. The weight of the soil that was retained on each sieve was measured after completing the shaking process in 10 minutes. The soil that passed through the finest sieve (63μm) was collected and undergone for hydrometer test. The

hydrometer test was conducted using the measuring cylinder (1000ml) and sodium silicate (Na2SiO3) as a dispersing agent. The test was performed using British Standard 377: Part 2:1990:9.6.

Grain size analysis can be used to estimates the hydraulic conductivity value. The grain-size methods use coefficients that are estimated from empirical data, as well as some kind of representative value of the grain size. The effective grain size, D_{10} from the distribution curve such as is used for the determination of the hydraulic conductivity.The values of hydraulic conductivity (K), was estimated using the methods proposed by Hazen (Hazen 1911) and Korzeny-Carmen although there are some other formula such as Beyer, Slitcher, Terzaghi, US Bureau of Reclamation (USBR) and Alyamani and Sen. Kozeny-Carman equation was introduced by Kozeny (1927), which then modified by Carman (1937,1956) to produce Carman equation. However, this equation is not suitable for efficient land with grain size exceeding 3mm or for clayey soil (Carrier, 2003). Equation by Hazen was originally used to determine the hydraulic conductivity of uniformly sized sand but it is also useful for grain size ranging from fine sand and silt that has coefficient uniformity less than 5 and effective grain size between 0.1 mm to 3.0 mm (Odong, 2007). The required soil parameters for estimating hydraulic conductivity were determined from the sieve analysis results of PW.

2.4. Permeability Test (Constant Head Test)

Permeability of a soil is a measure of its capacity to allow the flow of the water through the pore spaces between solid particles. Permeability or hydraulic conductivity refers to the ease with which water can flow through a soil. Hydraulic conductivity is the necessary parameter to estimate the travel time at different depths (Hazen, 1893). This test was conducted for soil sample of PW from depth 11 m to 33 m. The permeability constant head test was done in accordance with British Standard 1377: Part 1-9:1990. The degree of permeability is determined by applying a hydraulic pressure gradient in a sample of saturated soil and measuring the flow rate of the water. The soil was first oven-dried for 24 hours before placing in the column. The soil sample then poured into the permeameter. The internal diameter the of the permeameter cell were measured and recorded. The length and the weight of the specimen were also measured. The permeameter were placed at the test equipment and the water valves were opened. Water was allowed to flow constantly. A measuring cylinder was placed under the outlet of permeameter and the timer was started simultaneously. The levels of water in the manometer tubes which is H_1 and H_2 were recorded. The quantity of water collected in the measuring cylinder for a given time interval (30 s).

2.5. Pumping test

After development of the pumping well, the well should be tested for performance and aquifer properties. A pumping test program for PW was carried out on 8thApril 2014 until 12thApril 2014. A step-drawdown test (five steps), a 72-h constant discharge test, and a recovery test were done for the test well (PW). A submersible pump FRANKLIN model 65SR7F65-0463 was installed to a depth 22 m below ground level and a DENYO 20KVA generator set as the prime mover was used during the test. A gate valve was used to regulate discharge from the pump. Water level measurement during the testing process was performed using a dip meter with dial, sound and indicator light. After the installation of the pump and all other necessary set-up were completed, a calibration test was carried out for 2 hours to determine the capacity of the exploration test well and also to determine the pumping rates for the Step Drawdown Test. The Step Drawdown Test was done on 8th April 2014 with five discharging steps, with step 1 to step 4 for duration of 60 minutes, while step 5 was carried out for duration of 90 minutes. The Constant Discharge Test was done in duration of 72 hours started on 9th April 2013 and Recovery Test was carried out on 12thApril 2014.

3. RESULTS AND DISCUSSION

3.1. Aquifer information

Aquifer is a geologic unit that can store and discharge water at a rate of speed that can supply an amount of water that can be used by a well (Fetter, 2011). Most of the aquifer consists of the layers of granular medium to coarse sand with some gravel. The layers of sand and gravel make a good aquifer because its porosity and high permeability. Screen of the test wells and monitoring wells were placed on the layer of sand that forms the aquifer to allow groundwater flow into the well. Based on the drilling information, the study area consists of a layer of stiff clay at the top with a thickness ranging from ground level to 5 m depth. The next layer is consists of white sandy clay with thickness ranging from 5 m to 16 m depth. The layer ranging from 16 m to 31m depth consist of coarse sand to gravel. The bedrock of this study area was found at depth 33 m depth. Drilling log and design of the test well are shown in Figure 3. From the figure it shows that the gravel and coarse sand layers are overlain by the clay which makes the aquifer confined or semi-unconfined depending on the

location. The thickness of the aquifer ranges from 16 m to 33 m depth, and it can be locally heterogeneous because of the presence of beds of fine-to-coarse-grained sand. Generally there is only one layer of the aquifer in the study area.

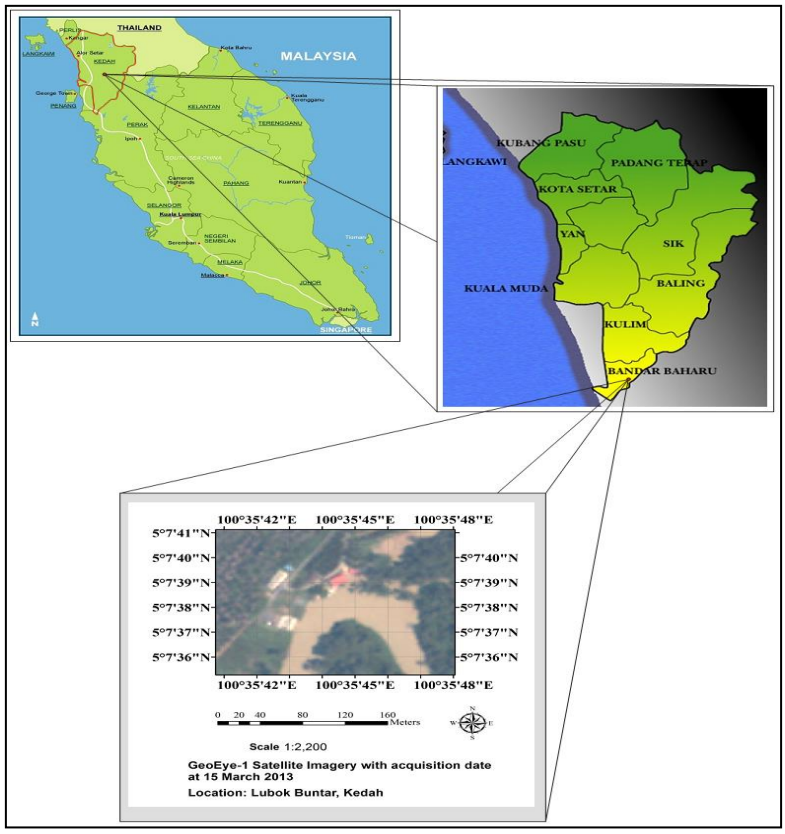

Fig 1: Location of the study area

Table 1: Soil Classification for borehole PW

Boreholes	Depth (m)	Soil types (% sample)									
		Gravel			Sand			Silt			Clay
		Coarse	Med.	Fine	Coarse	Med.	Fine	Coarse	Med.	fine	
PW	0-1m	0	0	8.9	28.3	10.2	5.9	15.9	4.5	10.0	1.8
	1-2m	0	0	4.6	29.7	12.9	7.4	10.2	3.6	9.0	22.6
	2-3m	0	0	1.7	17.9	11.8	23.8	8.5	6.4	16.4	0.0
	3-4m	0	0	3.0	19.6	10.9	8.5	0.0	5.1	5.6	7.5
	4-5m	0	0	4.4	22.3	11.2	6.4	1.7	5.3	3.5	4.4
	5-11m	0	0	5.8	37.1	12.9	9.1	2.7	5.4	20.6	0.0
	11-16m	0	0	3.6	32.4	13.7	9.9	4.4	3.5	22.7	0.0
	17-23m	0	0	45.6	29.9	10.9	2.5	4.6	2.1	5.0	0.0
	23-29m	0	0	19.0	59.0	11.5	3.6	2.9	1.7	2.5	0.0
	29-33m	0	0	25.6	46.1	20.2	2.0	1.1	0.8	4.1	0.0

3.2. Grain size analysis of soil samples

The results of the mechanical sieve analysis and the hydrometer test can be expressed in terms of the weight percentage of the soil particles to the total weight of the soil sample. Table 1 and Table 2 show the results of sieve analyses for PW and BH1 at the different depths. Table 1 show that PW has a proportion of fine gravel, coarse sand, medium sand and fine sand as 1.7 to 45.6%, 17.9 to 59%, 10.2 to 20.2% and 2.0 to 23.8 respectively. For proportion of coarse silt, medium silt, fine silt and clay for PW as 0 to 15.9%, 0 to 6.4%, 2.5 to 16.4% and 0 to 22.6% respectively. Table 2 shows the results of grain size

analysis for monitoring well BH1 at 1 m to 30 m depth. BH1 has a proportion of fine gravel, coarse sand, medium sand and fine sand ranging from 0 to 43.8 %, 9.2 to 78.9%, 3.1 to 56.3% and 1.7 to 59% respectively. For proportion of coarse silt, medium silt, fine silt and clay for BH1 the results ranging from 0.8 to 20.5%, 0 to 7%, 0 to 1.6% and 0 to 3% respectively. The grain size analysis results indicates the top layer to 16 m depth of PW and BH1 have higher percentage of silt and clay and it is consistent with the information of the drilling log. The soil from 16 m to 33 m depth for PW and 16 m to 30 m depth for BH1 has higher percentage of coarse sand and followed by medium sand and fine gravel. Therefore the main aquifer of this study area can be assumed to be from depth 16 m to 33 m.

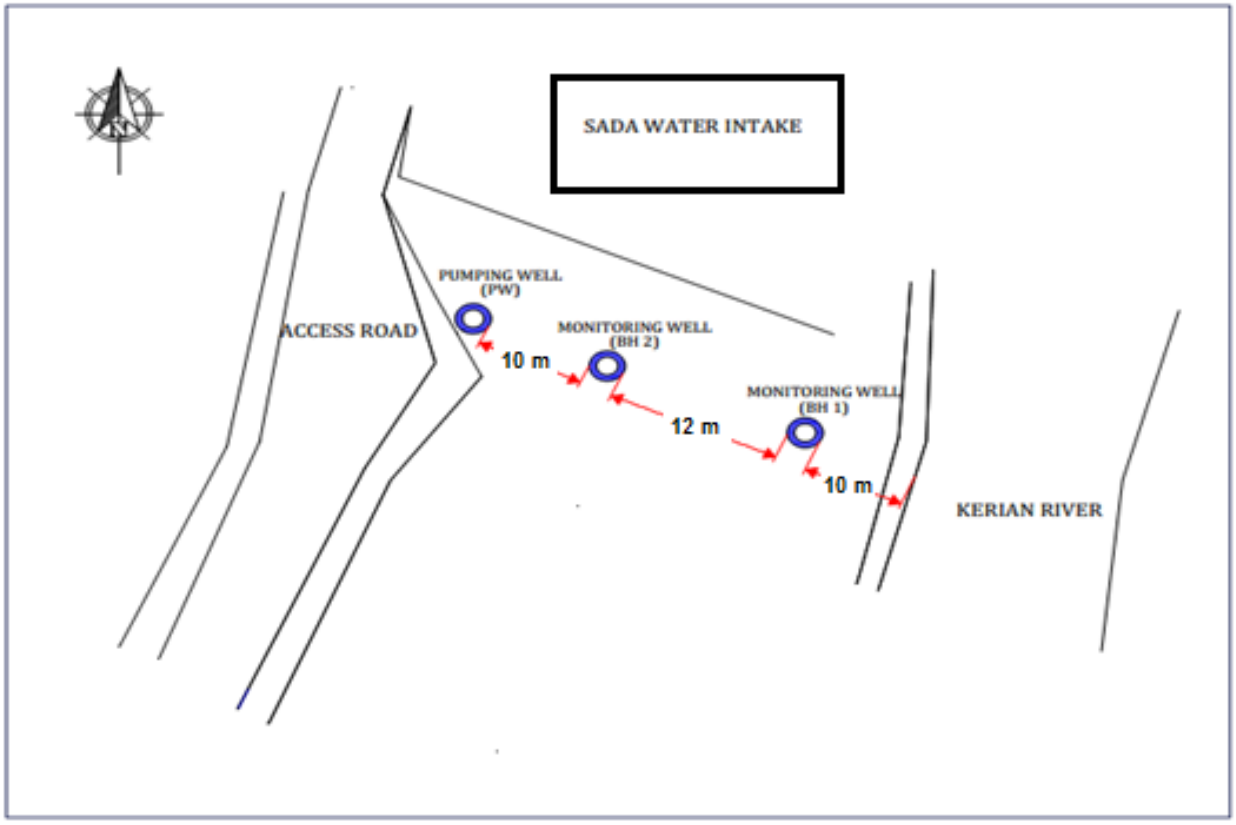

Fig 2: Location of pumping well (PW) and monitoring wells (BH1 and BH2)

3.3. Hydraulic conductivity (K) of grain size analysis

Data of the saturated hydraulic conductivity for PW are shown in Table 3. The values of hydraulic conductivity were estimated based on the Hazen and Kozeny-Carmen methods. The values for 11 m to 30 m depth were approximately 0.002 m/d to 150.81 m/d and 0.01 m/d to 4.96 m/d based on Hazen and Kozeny-Carman method respectively. The results indicate that the value of hydraulic conductivity increases according to the depth of the soil sample. This is because the layer from 11 m to 30 m depth consist high percentage of fine gravel, coarse sand and medium sand. The values of hydraulic conductivity (K), a necessary parameter to estimate the travel time at different depths. The travel time between the screens of the piezometers and/or test wells and the riverbank is an important parameter for bacteria and turbidity removal (Shamsuddin et al., 2014). Schijven and Majid Hassanizadeh (2000) stated that, a 60-day travel time was assumed to be adequate to inactivate pathogenic bacteria to the degree that no health risk exists. In a study in Nainital, India, where groundwater tube wells are located 84 m from the lake bank, the travel time was found to be 1–2 days. A travel time between 10–20 days was needed in India to reach 4–5 log removal of coliform during BI and in Germany, a travel time of 50 days is commonly recommended for the elimination of bacteria and to design a water-protection zone where no microbial pollution should occur (Dash et al., 2008).

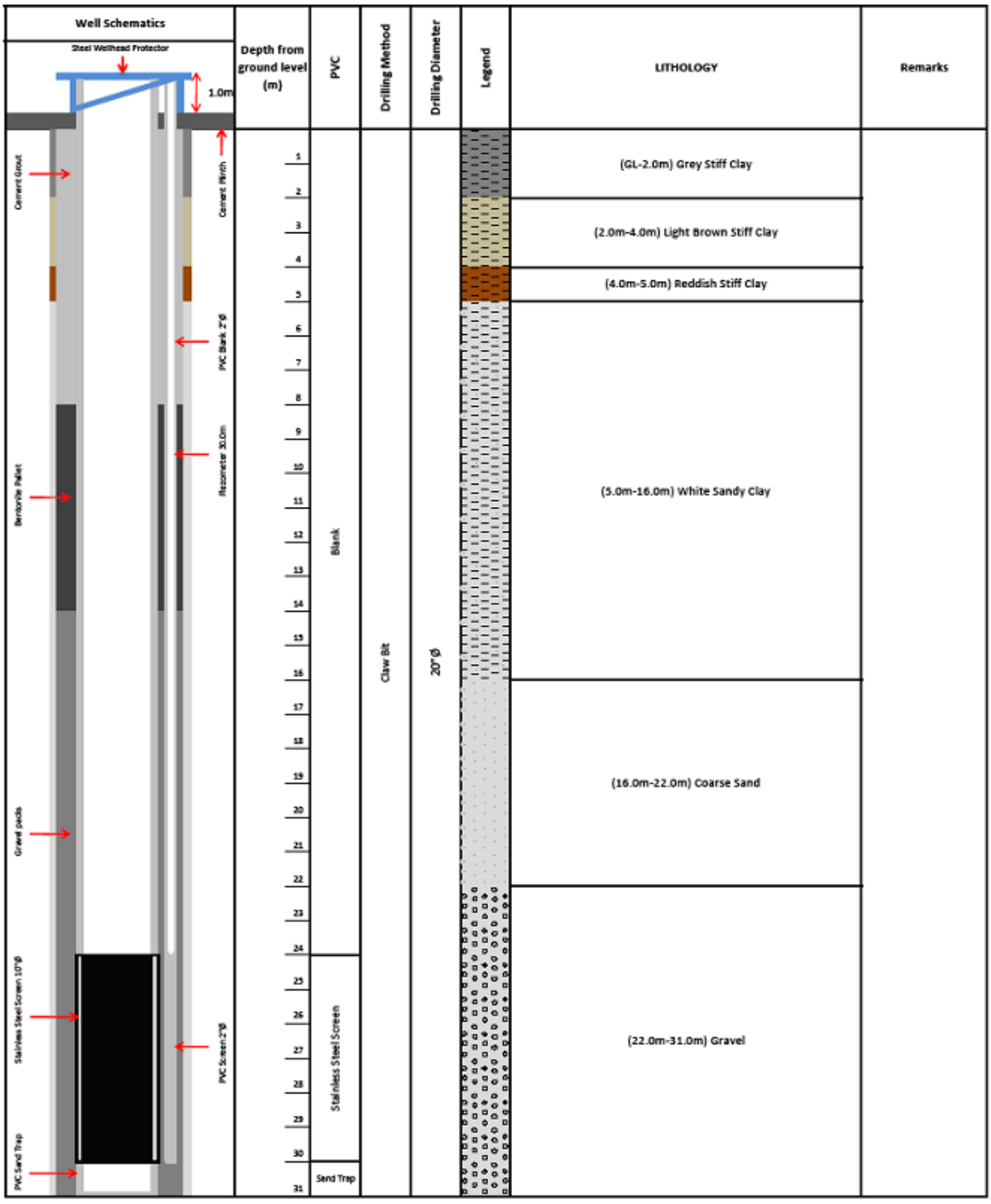

Fig 3: Drilling log and well design of the test well (PW)

3.4. Permeability (Constant head test)

Table 4 shows the result of permeability from constant head test for PW at 11 m to 33 m depth. From the test, the results showed that the permeability of the soil sample of PW at depth of 11 m to 16 m, 17 m to 23 m, 23 m to 29 m and 29 m to 33 m were 4.1902 x10^{-5} m/s, 1.2221x10^{-4} m/s, 1.2197x10^{-4} m/s and 1.2555x10^{-4} m/s respectively. The literature indicates that an alluvial aquifer near the river such as the Rhine River often have a hydraulic conductivity of 10^{-3} to 10^{-2} m/s (Schubert, 2006; Price et al., 1999). In previous RBF applications, the hydraulic conductivity, k, of Illinois River, USA had ranged between 2×10^{-3} and 3×10^{-3} m/s. The Ohio River in Louisville, Kentucky, USA had a k value of 6×10^{-4} m/s, while the value for Great Miami River in Cincinnati, USA ranged between 8.8×10^{-4} and 1.5×10^{-3}m/s (Dash et al., 2008).

Table 2: Soil Classification for borehole BH1

Boreholes	Depth (m)	Soil types (% sample)									
		Gravel			Sand			Silt			Clay
		Coarse	Med.	Fine	Coarse	Med.	Fine	Coarse	Med.	Fine	
BH1	1m	0.0	0.0	0.6	23.8	15.2	10.0	15.2	3.6	9.0	3.0
	2m	0.0	0.0	0.0	29.1	25.8	4.7	11.5	6.3	6.3	1.8
	3m	0.0	0.0	0.0	17.9	19.3	33.4	8.0	3.4	7.7	0.0
	4m	0.0	0.0	0.1	32.7	3.1	20.9	13.6	7.0	12.2	1.7
	5m	0.0	0.0	1.8	41.2	3.3	8.5	20.5	5.7	9.5	1.9
	7m	0.0	0.0	0.0	31.1	33.2	23.1	4.5	0.8	2.4	0.0
	8m	0.0	0.0	0.0	32.6	22.9	16.0	12.1	2.1	6.2	1.8
	9m	0.0	0.0	0.2	23.3	15.9	18.4	17.6	6.2	12.3	0.0
	10m	0.0	0.0	0.3	58.9	22.8	12.1	0.9	0.0	0.0	0.0
	11m	0.0	0.0	0.4	52.1	23.3	16.0	1.2	2.0	0.0	0.0
	12m	0.0	0.0	0.3	38.2	22.6	27.8	5.4	0.8	0.0	0.0
	14m	0.0	0.0	0.0	45.2	25.2	16.4	4.0	0.5	2.0	0.8
	15m	0.0	0.0	0.0	26.6	56.3	11.6	5.5	0.0	0.0	0.0
	16m	0.0	0.0	0.0	23.9	29.5	32.8	9.3	4.5	0.0	0.0
	17m	0.0	0.0	0.1	54.2	32.5	11.4	1.8	0.0	0.0	0.0
	18m	0.0	0.0	0.0	59.9	25.0	13.0	2.1	0.0	0.0	0.0
	19m	0.0	0.0	0.0	68.1	21.4	8.5	2.0	0.0	0.0	0.0
	20m	0.0	0.0	0.0	78.9	18.4	1.7	1.0	0.0	0.0	0.0
	21m	0.0	0.0	0.2	76.1	16.6	5.3	1.8	0.0	0.0	0.0
	22m	0.0	0.0	0.4	71.3	15.9	9.5	2.9	0.0	0.0	0.0
	24m	0.0	0.0	0.0	70.1	17.6	9.9	0.8	0.0	1.6	0.0
	25m	0.0	0.0	0.1	13.2	27.1	47.2	5.9	4.3	2.2	0.0
	26m	0.0	0.0	43.8	42.8	5.8	2.0	1.2	0.2	4.3	0.0
	27m	0.0	0.0	0.1	17.2	23.6	45.1	6.4	1.1	6.5	0.0
	28m	0.0	0.0	0.0	10.4	19.8	59.0	6.6	4.2	0.0	0.0
	29m	0.0	0.0	0.0	9.2	23.8	55.6	3.9	2.3	0.0	0.0
	30m	0.0	0.0	0.4	19.6	24.7	44.1	5.0	2.9	3.3	0.0

Table 3: Values of hydraulic conductivity based on Hazen (1911) and Kozeny (Korzeny 1927) and Carman (1983, 1956). D_{10}, D_{20}, D_{50} and D_{60} values obtained from grain size analysis

Well	Depth (m)	Characteristics grains				Hazen		Kozeny-Carman	
		D_{10}	D_{20}	D_{50}	D_{60}	m/s	m/d	m/s	m/d
PW	11-16m	0.002	0.003	0.298	0.517	.231E-07	0.002	.112E-06	0.01
	17-23m	0.042	0.463	1.679	2.401	9.95E-06	0.86	5.82E-06	0.5
	23-29m	0.267	0.557	1.104	1.357	8.22E-04	70.99	6.92E-05	5.44
	29-33m	0.371	0.514	1.211	1.534	1.75E-03	150.81	5.74E-05	4.96

3.5. Capacity of abstraction

Step Drawdown Test was carried out with pumping rate at 12.247 m^3/hour, 15.938 m^3/hour, 20.226 m^3/hour, 25.141 m^3/hour and 30.71 m^3/hour. The initial static water level before the Step Drawdown Test was 3.79 m below ground level and the final water level was at 17.38 m below ground water level. According to the results of the Step Drawdown Test the Constant Discharge Test was selected based on Step 5 which at 30.71 m^3/hour. The flow rate was kept constant throughout the test for duration of 72 hours. Thus the overall rate for the production well is 0.737 MLD. Constant Discharge

Test was performed on the test well PW to determine the aquifer characteristics such as hydraulic conductivity and transmissivity. The hydraulic conductivity and transmissivity were also compared and calculated for the steady-state flow based on the analysis of the first step test (achieved drawdown by different pumping rates), for the steady state (a later stage of pumping), and for the recovery test (almost immediate recovery after pumping) (Shamsudin et al 2014). The results are shown in Table 4. Based on this analysis, the hydraulic conductivity for Step Test ranged from 15.81 m/d to 79.34 m/d and the transmissivity ranged from 268.80 m^2/d to 1348.80 m^2/d. The hydraulic conductivity and transmissivity increasing parallel with the increase of flow rate. For Constant Discharge Test, the hydraulic conductivity and transmissivity were 7.86 m/d and 133.57 m^2/d. The initial static water level was at 3.90 m below ground level and the final water level after 72 hours of continuous pumping was at 16.89 m below ground level with the drawdown 12.99 m. Hydraulic conductivity and transmissivity can be also obtained from the analysis of Recovery test. Recovery Test was carried out immediately after the Constant Discharge Test ends. The transmissivity and hydraulic conductivity value from Recovery Test were 44.09 m^2/d and 2.59 m/d respectively.

Table 4: Permeability results from constant head test for PW

Depth, m	Permeability, K (m/s)
11-16m	4.1902E-05
17-23m	1.2221E-04
23-29m	1.2197E-04
29-33m	1.2555E-04

Table 5: Result of pumping test for the value of transmissivity, T and hydraulic conductivity, K

Test	Date	Well	Drawdown (m)	Transmissivity, T (m^2/d)	Hydraulic Conductivity (m/d)
STEP TEST 1	8th April 14	PW	3.62	268.80	15.81
STEP TEST 2	8th April 14	PW	5.02	699.84	41.17
STEP TEST 3	8th April 14	PW	6.65	741.74	43.63
STEP TEST 4	8th April 14	PW	10.59	1292.64	76.04
STEP TEST 5	8th April 14	PW	13.59	1348.80	79.34
Constant Discharge Test	9th April 14- 12th April 14	PW	12.99	133.57	7.86
Recovery Test	12th April 14	PW	0.02	44.09	2.59

4. CONCLUSION

A typical aquifer of a riverbank alluvial deposit considered for RBF application was investigated for the characteristic of its soil samples. The grain size analysis of samples for PW and BH1 indicates the proportion of soil at different depth. The results shown that the top layer to 16 m depth of PW and BH1 have high percentage of silt and clay and it is consistent with the information of the drilling log. The soil from 16 m to 33 m depth for PW and 16 m to 30 m depth for BH1 have high percentage of coarse sand and followed by medium sand and fine gravel. Therefore the main aquifer of this study area could be assumed to be from depth 16 m to 33 m. The values of hydraulic conductivity based on Hazen and Kozeny-Carmen methods were approximately 0.002 m/d to 150.81 m/d and 0.01 m/d to 4.96 m/d respectively. Hydraulic conductivity increases according to the depth of the soil sample because of the layer from 11 m to 30 m depth consists high percentage of fine gravel, coarse sand and medium sand. From the permeability test, soil samples of PW have permeability in ranged 4.1902 x10^{-5} m/s (3.62 m/d) to 1.2197x10^{-4} m/s (10.54 m/d). For Constant Discharge Test, the hydraulic conductivity and transmissivity were 7.86 m/d and 133.57 m^2/d respectively. Thus the overall rate for the production well is 0.737 MLD. Based on the result of alluvial soil characteristics and properties, the implementation of RBF at this study site as a pre-treatment for increasing water quality is proven. Further work is needed to build a big RBF

system construction such as Horizontal collector well (HCW) to get higher water quantity for water supply demand. The efficiency of BI depends on local conditions such as the hydrology and hydrogeology of the site, the geochemistry of the water (from both the river and the aquifer), and the characteristics of the microbial populations and associated metabolic activity. Thus, field investigation is important to determine the potential and expected efficiency of the BI process. Although BI has been used in Europe for more than a century, the current understanding of the process and mechanisms behind this technique in tropical countries is almost nonexistent. The potential of BI in tropical countries can be established by studying, in particular, the various types of geological data, sieve (particle size) analysis and pumping test data. Other extensive investigation should be conducted such as geophysical data, isotope analysis, colloidal borescope data (to determine the local direction of flow at the well), and water-quality analysis of the bank filtered water to determine the effectiveness of RBF system at the study area.

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