Jurnal
Teknologi

Full Paper

A Study On The Potential Of Riverbank Filtration For The Removal Of Color, Iron, Turbidity And *E.Coli* In Sungai Perak, Kota Lama Kiri, Kuala Kangsar, Perak, Malaysia

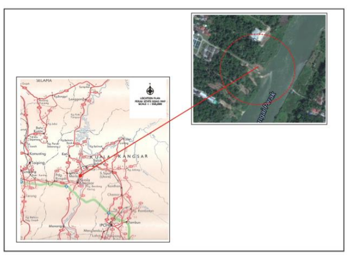
Article history
Received
24 April 2015
Received in revised form
4 May 2015
Accepted
9 May 2015

Siti Zahirah Othman*, Mohd Nordin Adlan, Mohamad Razip Selamat

School of Civil Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia

*Corresponding author
szo13_civ013@student.usm.my

Graphical abstract



Abstract

Riverbank filtration technology in securing water resource is still new to some developing countries such as Malaysia. This research has been carried out at Kota Lama Kiri in the Kuala Kangsar, Perak, Malaysia to study the removal on the turbidity, iron, color, and *E.coli* by riverbank filtration. Characteristics of soil samples from pumping well (PW) was investigated. The soil samples were collected during the development and construction process of the PW. The water quality analyses were performed on site during the pumping test program. The soil samples collected were transported to the Geotechnical Engineering Laboratory, Universiti Sains Malaysia where sieve analyses and permeability test were performed with reference to BS 1377: Part 2:1990. Results of sieve analyses shows that the value of Cu (coefficient of uniformity) for the PW was found to be within the range of 2.40 to 3.75 mm while the value of Cc (coefficient of gradation) lies in the range of 0.06-0.35 mm. The ANOVA One Way Test for soil strata of the PW was performed using MINITAB statistical packages and the results indicate that the p-value was 0.996. It was found that there were no significance differences between the mean size of soil samples from different depths within the PW. The hydraulic conductivity, k value for PW ranges between 0.10-5.65 cm/s. Removal of turbidity, color, iron, and *E.coli* were 98.78%, 73.56%, and 87.93%, respectively. In this study, the highest removal efficiency of *E.coli* was found to be 100%.The overall well production from the pumping test was found 112.10 m^3/hr.

Keywords: Riverbank filtration, turbidity, color, iron, E.coli

Abstrak

Teknologi penapisan tebing sungai dalam mendapatkan sumber air masih baru kepada beberapa negara-negara membangun seperti Malaysia. Kajian ini telah dijalankan di Kota Lama Kiri di Kuala Kangsar, Perak, Malaysia bagi mengkaji kadar penyingkiran pada kekeruhan, besi, warna, dan E.coli oleh penapisan tebing sungai. Ciri-ciri daripada sampel tanah dari perigi pam (PW) telah dikaji. Sampel tanah juga telah dikumpulkan semasa pembangunan dan pembinaan proses PW. Analisis kualiti air telah dijalankan di lokasi semasa program ujian pengepaman. Sampel tanah yang diambil telah dihantar ke Makmal Kejuruteraan Geoteknik, Universiti Sains Malaysia untuk analisis ayak dan ujian kebolehtelapan telah dijalankan dengan merujuk kepada BS 1377: Part 2: 1990. Keputusan analisis ayak menunjukkan bahawa nilai Cu (pekali keseragaman) bagi PW didapati dalam julat 2.40 hingga 3.75 mm manakala nilai Cc (pekali penggredan) terletak dalam julat 0.06 hingga 0.35 mm. ANOVA Ujian Sehahala untuk tanah strata PW dilakukan dengan menggunakan MINITAB pakej statistik dan keputusan menunjukkan bahawa nilai-p adalah 0.996. Ia telah mendapati bahawa tidak terdapat perbezaan yang signifikan antara saiz min sampel tanah dari kedalaman yang berbeza dalam PW. Kekonduksian hidraulik, nilai k untuk PW berkisar antara 0.10-5.65 cm/s. Penyingkiran kekeruhan, warna, besi, dan E.coli adalah masing-masing 98.78%, 73.56%, dan 87.93%. Dalam kajian ini, kecekapan penyingkiran tertinggi E.coli didapati sebanyak 100%. Pengeluaran telaga secara keseluruhan daripada ujian pengepaman didapati sebanyak 112.10 m^3/ jam.

Kata kunci: Tebing sungai, penapisan, kekeruhan, warna, besi dan E.coli

1.0 INTRODUCTION

1.1 Riverbank Filtration

Riverbank filtration technology has been a common practice in Europe for over 100 years, particularly in countries such as Switzerland where 80 % of drinking water comes from RBF wells, 50 % in France, 48 % in Finland, 40 % in Hungary, 16 % in Germany, and 7 % in the Netherlands [1]. In Germany, for example, 75 % of the city of Berlin depends on RBF, whereas in Düsseldorf RBF has been used since 1870 as the main drinking water supply [2]. In the United States, on the other hand, this technique has been used for nearly half a century, especially in the states of Ohio, Kentucky, Indiana, Illinois, among others [3]. Other countries that have recently started implementing RBF for drinking water supply are India [4],China, and South Korea [5].

For a developing country such as Malaysia, RBF technology was still new and only few efforts have been made so far to understand the RBF mechanism and processes. A gap in water abstraction knowledge on RBF needs to be explored in order to provide better alternative for water security sources. The use of conventional treatment system with regards to RBF also needs to be explored so that process optimization could be achieved for different treatment units. Peninsular Malaysia is drained by a dense network of rivers and streams (there are about 150 major river basins). Major rivers drains into the South China Sea are the Kelantan, Terengganu, Dungun, Endau, and Sedili rivers. Major river basins in the east of Malaysia tend to be larger than those in Peninsular Malaysia. Out of an annual rainfall volume of 990 km^3, 360 km^3 (36 percent) are lost to evapotranspiration. The total surface runoff is 566 km^3, and about 64 km^3 (7 percent of the total annual rainfall) contribute to groundwater recharge. However, about 80 percent of the groundwater flow returns to the rivers and is therefore not considered an additional resource. The total internal water resources of Malaysia are estimated at 580 km^3/year. This shows that protection to river and groundwater are very important in order to obtain a sustainable water usage. River bank/bed filtration (RBF) offers a good practice to treat and protect the surface water as well as groundwater. It is because; RBF uses the bed of a reservoir, lake or river and an adjacent sand and gravel aquifer as a natural filter. The technology can be applied directly to existing surface water reservoirs, streams, lakes and rivers, and now it is often a guiding factor in the hydrogeologic investigation of new source supplies.

Riverbank filtration is a natural process used as a first step in drinking water treatment. During the process, the river water passes through riverbed and aquifer sediments that serve as natural filters, and various contaminants such as trace organic pollutants, bacteria, viruses, and inorganic compounds are removed [6]. The process of bank filtration was initiated by the lowering of a groundwater table below that of an adjoining surface water table. Provided that no artificial such as brick or concrete lined bed or natural, as for example a low hydraulic conductivity layer such as clay barriers exist, the difference in water levels causes the surface water to infiltrate through the permeable riverbed and bank or lakebed into the aquifer. The infiltration may be the direct result of an influent river under natural conditions or it may be induced by purpose built groundwater extraction wells or tube wells. Wells for extracting bank filtrate may be either vertical or horizontal.

Bank filtration has been shown to be effective in removing many of the contaminants present in surface water. Studies have shown that bank filtration is a highly efficient method for significant removal of turbidity [7, 8, 9], natural organic matter (NOM), pesticides, and pharmaceuticals [10, 11, 12, 13, 14, 15, 16], salinity [17]; as well as taste and odor causing compounds, which may not be removed from the surface water by conventional treatment methods [18, 19]. The potential of RBF systems to provide a significant barrier to microorganisms has also been observed [20, 21, 22, 23, 24, 25, 26, 27, 28] and it has been proven to significantly reduce the presence of *Giardia* and *Cryptosporidium* for drinking water applications when flow path length and filtration times are sufficient [29, 30, 31]. The applications of the RBF has been done widely because of its potential to transfom the river water into drinking water grade by improving the water quality using the natural process. Water quality analyses have been conducted extensively worldwide to focus on the removal efficiency using RBF. Shweta *et al*., (2013) studied the river water quality in Uttarakhand, India. It was found that the concentration of iron in river water samples were between 0.01 to 0.18 mg/l, whereas in RBF well water these concentrations varied from 0.03 to 0.06 mg/l during the monitoring course. All these values were much lower than the desirable as well as permissible limits for iron. Locations near the study area have been found to contain a higher amount of iron in different water supply schemes and hand pumps and even samples have been reported to possess orange/red color. The effectiveness of RBF in iron content reduction may be used as a tool for an iron removal method at large scale without any disposal problem or associated disadvantages of existing iron treatment techniques.

RBF process also helps in the reduction in particle and pathogen count and turbidity of source water. Shamrukh and Abdel-Wahab (2008) compared the physical, chemical, and microbiological qualities of RBF water with river water and background natural groundwater in a Nile valley region of Upper Egypt. They demonstrated that the RBF water qualities were superior to those of the other waters, especially in terms of turbidity, total coliform, and *Escherichia coli (E.coli)*. Wang *et al*., (1995) observed *E.coli* removal up to 2.4 log units from the Ohio River water. Mikels (1992) reported the turbidity of the pumped water from the collector well Kalama, Washington in the range of 0.3 to 0.4 Nephelometric Turbidity unit (NTU) and during the same time, the Columbia River Water turbidity varied between 1.0 and 5.0 NTU. The laterals of the wells were located only 6 m below the riverbed. Miettinen *et al*. (1996) observed strong reductions in bacterial enzymatic activities after infiltration of lake water into an aquifer. They also observed a reduction in biomass production and bacterial cell counts. Havelaar *et al.* (1995), over a 7 months monitoring of *enteroviruses* at a bank filtration plant, reported that bank filtration easily provided 4 log removal of *enteroviruses*. They observed better (5-6 log removal) performance of bank filtration for removing F-specific RNA coliphages.

1.2 Site Description

Kuala Kangsar site was selected for RBF application after considering the soil profile near the Sungai Perak. For the application of the RBF at Kuala Kangsar site, the pumping well (PW) and monitoring wells (MW) were designed to locate perpendicular to the riverbanks of the Sungai Perak. Table 1 shows the well information and description in the studied location. PW serves as the main source of water abstraction while MW`s were developed to study the recharge effects and water level drawdown during the pumping test. As shown in the Figure 1, the distance from the MW1 to the river was 10 meter. The distance between MW1 and MW2 was 8 meter, where the distance were applied similar to all of the monitoring wells, except for MW5 and MW6 .The distance of MW5 from the PW was 25 meter, and 50 meter for the MW6, respectively. MW1, MW2, PW, MW3 and MW4 were developed adjacent (90°) to the banks of the Sungai Perak while the development of the MW5 and MW6 takes 45° from the PW.

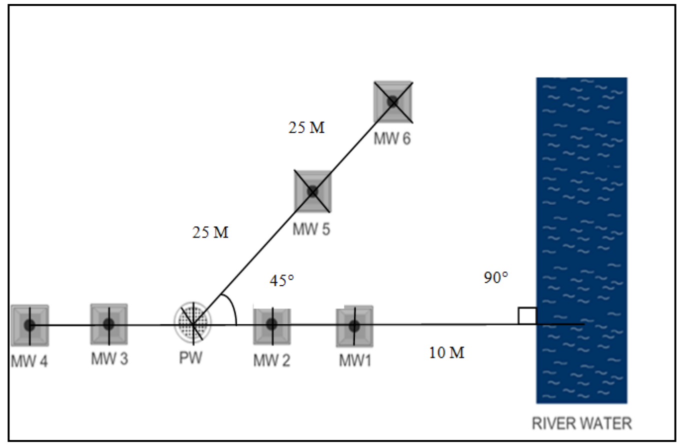


Figure 1 Location of the study area with wells

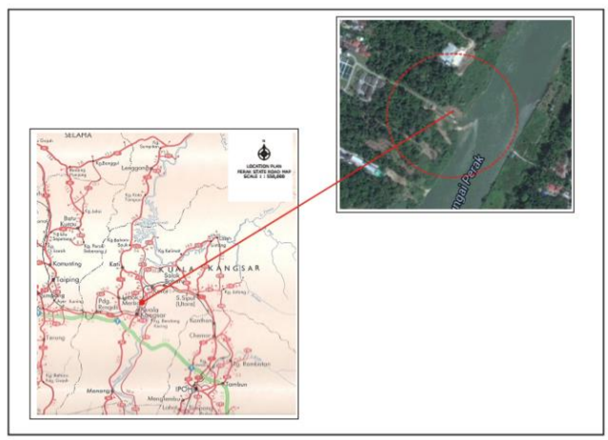


Figure 2 Location of the study site at the Kota Lama Kiri, Kuala Kangsar, Perak

Table 1 Wells information and description in Kota Lama Kiri, Kuala Kangsar

Well Identification	Longitude And Latitude	Depth of well (m)	Screen position (m)	Distance from PW (m)	Well collar (m)	Static water level (m)	Rate of pumping (m^3/hour)
Pumping Well (PW)	04°48'08.5''N and 100°57'06.9''E	8 m	5-8	-	0.65	1.81	112.10
Monitoring Well 1 (MW1)	04°48'08.3''N and 100°57'07.3''E	3.34	1.34-3.34	16 m	0.52	1.99	112.10
Monitoring Well 2 (MW2)	04°48'08.4''N and 100°57'07.3''E	2.85	1.35-2.85	8 m	0.55	1.65	112.10
Monitoring Well 3 (MW3)	04°48'08.7''N and 100°57'06.3''E	4.05	2.55-4.05	8 m	0.55	1.65	112.10
Monitoring Well 4 (MW4)	04°48'08.7''N and 100°57'06.3'' E	3.35	1.85-3.35	16 m	0.54	1.91	112.10
Monitoring Well 5 (MW5)	04°48'08.8''N and 100°57'07.6''E	3.02	1.52-3.02	25 m	0.54	1.46	112.10
Monitoring Well 6 (MW6)	04°48'09.2''N and 100°57'08.2''E	2.78	1.28-2.78	50 m	0.54	1.01	112.10

2.0 EXPERIMENTAL

2.1 Soil Sampling and Soil Investigation

As shown in Figure 2, soil sample were collected during the construction and development of the PW in Kuala Kangsar, Perak. The coordinate of the PW were 04°48'08.5''N and 100°57'06.9''E .The samples were collected for each meter depth as the drill penetrates deep into the ground. The soils sample in each layer were collected and labelled. Maximum depth of PW borehole was 13 metres. The soil samples were transported to the Geotechnical Engineering Laboratory in School of Civil Engineering, Universiti Sains Malaysia (USM) where sieve analyses (BS 1377: Part 2:1990) and permeability test (BS1377: Part 1-9:1990) were conducted.

2.2 Pumping Test

The pumping test was carried using a DT 95-10 Dynatech Submersible Pump. A Submersible Pump was installed by using a crane to a depth of 9.5 meter below ground level and 125 mm diameter GI riser pipes were connected to the submersible pump. A 125 mm diameter gate valve was connected to the riser pipe to regulate the flow rate. The riser pipes were then directed to a 90 V Notch tank to measure the flow rate of pumping. After the installation of the pump and all other necessary setup was completed, a calibration test was carried out for 2 hours to determine the capacity of the pumping wells, and also to determine the pumping rates for the Step Drawdown Test. The pumping test programme consists of step drawdown and a 72 hours constant discharge test and recovery test. The constant discharge test was carried out at a pumping rate of 112.10 m^3/hour.

2.3 Sampling Collection and Handling

Groundwater samples were collected after every 12 hours in clean plastic bottles and sent to the laboratory for the chemical and physical analyses, as well as for the presence of *E.Coli* and Total Coliform bacteria. The groundwater samples collected were from the PW and MW`s. River water were also collected along to investigate the quality of surface water. Total of 48 groundwater samples were collected during the pumping test. Each groundwater sample consists of two liters of raw groundwater sample and one liter of groundwater sample acidified with 50% HNO_3 to a pH less than two as a preservation. For *E.coli* and Total Coliform bacteria test, the groundwater and river water samples were collected in sterilized swirl pack which were then packed in ice, and were sent to the laboratories immediately after collecting the samples.

2.4 Water Quality Analyses

In this study, certain water quality parameters were selected. The water quality parameters are turbidity, iron, color and *E.coli*. During the sampling procedure, water samples were collected for the water quality analyses in the laboratory. Turbidity was done in accordance to Standard Method 2130B using turbiditimeter, color (Standard Method 2120C), iron (USEPA Ferrover® Method) and *E.coli* (IDEXX Colilert ® Test Method). *E.coli* was enumerated using the Quanti-Tray enumeration procedure. Color and iron test was carried out using DR2800 Spectrophotometer.

3.0 RESULTS AND DISCUSSION

3.1 Sieve analyses for soil samples and ANOVA (Analyses of Variance) Test

Grain size analyses were carried out in the Geotechnical Engineering Laboratory, School of Civil Engineering, Universiti Sains Malaysia (USM). Figure 3 shows the graphs of the particle size distribution (PSD) for soil samples from depth 0 -13 metre in a PW borehole. The transition of the distribution was found to be skewed more on the left side of the graph.

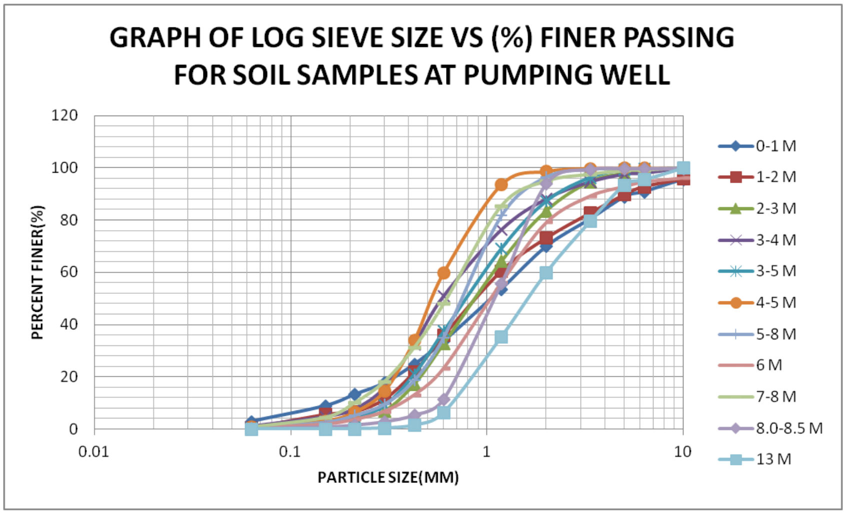


Figure 3 Graph of log sieve size vs % of finer passing for soil samples at PW

Table 2 Sieve analyses results for PW

Depth (m)	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c
3-4	0.30	0.40	0.80	2.67	0.06
3-5	0.25	0.40	0.60	2.40	0.07
4-5	0.38	0.70	1.20	3.16	0.15
6	0.37	0.75	1.30	3.52	0.16
7-8	0.20	0.40	0.75	3.75	0.14
13	0.69	1.0	2.00	2.90	0.35

Table 3 ANOVA one way results for PW

Source	DF	SS	MS	F	P
Factor	10	3623	362	0.20	0.996
Error	132	241694 1831			
Total	142	245317			
S = 42.79					
R^2 = 1.48%					

Table 4 ANOVA two-way results (FINER PASSING versus DEPTH, WELL)

Source	DF	SS	MS	F	P
DEPTH	3	912	304.13	0.19	0.906
WELL	6	19684	3280.60	2.00	0.065
Interaction			18	15643	869.04 0.943
Error		336	550073	1637.12	
Total		363	586311		
S = 40.46					
R^2 = 6.1					

D_{10} represents the 10% of the particles are finer and 90% of the particles are coarser than that particular size of D_{10}. D_{30} means 30% of the particles are finer and 70% of the particles are coarser than that particular size of D_{30}. The uniformity coefficient, termed as C_u, is the ratio of D_{60} to D_{10}.The samples were classified as well graded soil when they have the value of C_u greater than 4 to 6, which is C_u>4-6. Otherwise, the samples were said to be poorly graded while the value of C_u is less than 4, termed as

C_U<4. This soil samples also known as uniformly graded. The samples were said to be uniformly graded as the value of C_U is closer to 1. Well graded soil means the samples comprises of different sizes of particle distribution. Poorly or uniformly graded samples shows the sample comprises of same or equivalent sizes of particles. C_c is another measurement of gradation, which is coefficient of gradation. For the well graded samples, the C_U value must be greater than 4; and the C_c value must be in the range of 1 to 3. River deposits may be well-graded or poorly graded. Uniformly or gap-graded soil depends upon the water velocity, the velocity with which the particles are being drifted and the volume of the suspended solids, and the river area where the deposition occurred. Table 2 shows the sieve analyses result of soil samples within the PW. Laboratory results shows that the C_U value (3.75) for the depth of 7-8 metres was the highest among the soil samples from depth of 0 to 13 m. This result shows that the C_U value was less than 4. The C_c value is 0.14, thus samples from depth 7-8 metres can be described as uniformly graded soil . The ANOVA One Way Test and Two Way Test were conducted by using the MiniTAB statistical software packages. The result output shows that for PW, the p-values was found to be more than 0.05. Table 3 shows the p-value for PW was found 0.996 . From Table 4, the p-value for PW was found 0.906. In this case, we would accept the null hypothesis at 5% level of significance where there is no significance difference between the means of the soil layers in the PW.

3.2 Constant Head Permeability Test

Constant head permeability test was conducted for all the soil samples from depth 0-13 metre within PW in the Geotechnical Engineering Laboratory, School of Civil Engineering, Universiti Sains Malaysia (USM). Permeability or hydraulic conductivity, k was a measurement of flow within a soil sample. The hydraulic conductivity, k value for PW ranges between 0.10-5.65 cm/s. The hydraulic conductivity results for the PW were tabulated in the Table 5. The highest hydraulic conductivity was at the depth of 6 metres which is 0.91 cm/s. Alluvial gravel aquifers near rivers often have hydraulic conductivity of 10^{-3} to 10^{-2} m/s (e.g., the River Rhine, Schubert, 2006 and Shankar *et al*., 2009). The value of hydraulic conductivity at the temperature of 20°C is 0.74 cm/s.

Table 5 Permeability test results for PW

Depth (m)	**Hydraulic conductivity,k (cm/s)**	**Hydraulicconductivity,k (cm/s)@20°C**
2-3	5.65	4.60
3-4	0.15	0.12
3-5	0.15	0.12
4-5	0.26	0.21
6	0.91	0.74
7-8	0.10	0.08

Table 6 Water quality parameter removal percentage results during pumping test

Date	27/9/2013 30/9/2013		28/9/2013		29/9/2013	
Time	1500 HRS	0300 HRS	1500 HRS	0300 HRS	1500 HRS	1500 HRS
Parameters	% Removal	% Removal	% Removal	% Removal	% Removal	% Removal
Turbidity	94.76	97.44	98.78	96.83	97.49	92.87
Color	48.35	73.56	35.78	0	50	38.46
Iron	-12.38	-27.14	-32.54	87.93	55.79	55.79
E.Coli	0	100	100	100	100	99.73

Table 7 Water quality analyses results during pumping test

Date	27/9/2013 30/9/2013				28/9/2013				29/9/2013			
Time	1500 HRS		0300 HRS		1500 HRS		0300 HRS		1500 HRS		1500 HRS	
Parameters	RW	PW	RW	PW	RW	PW	RW	PW	RW	PW	RW	PW
Turbidity	21.4	1.12	18.4	0.47	15.6	0.19	18	0.57	18.7	0.47	16.7	1.19
Color	91	47	87	23	109	70	22	22	48	24	26	16
Iron	0.59	7.9	7	8.9	6.79	9	8.2	0.99	19	8.4	9.5	4.2
E.Coli	<1	<1	435.2	0	727	<1	387.3	0	344.8	<1	365.4	1

Table 6 and 7 shows the water quality results comprises of four main water quality parameters such as turbidity, color, iron and *E.coli.* For river water (RW), the highest turbidity reading was found to be 18.7 NTU which is on the fifth sampling hour (1500 HRS, 29/9/13). The high RW turbidity value may results from the runoff that occurred after the precipitation. Turbidity in water was caused by presence of suspended and dissolved matter, such as clay, silt, finely divided organic matter, plankton and other microscopic organisms, organic acids, and dyes that may be present from source water as a consequence of inadequate filtration (ASTM International 2003). The turbidity reading shows lowest reading on 0300 HRS, 29/9/13 which is 0.57 NTU. From the first sampling time which was on 1500 HRS, 27/9/13 until 1500 HRS, 30/9/13, the turbidity reading for river water does not show any obvious difference except for the forth sampling time which was on 0300 HRS, 29/9/2013. The lowest turbidity reading for the PW was found to be on 1500 HRS, 28/9/13 which was 0.19 NTU. For PW, the highest turbidity reading was 18 NTU on the sampling hour of 0300 HRS, 29/9/13. The reading for the sampling time of 0300 HRS and 1500 HRS on 28 and 29 September 2013 were both same (0.47 NTU). The turbidity pattern shows the low removal at the first sampling time of pumping test and then the value suddenly increased at the middle of pumping test and then the reading decreased again to 1.19 NTU at the end of the pumping test. During all of the sampling times, the removal of turbidity was up to 90% and above, where the maximum turbidity removal was 98.78% during the second day of pumping test on 1500 HRS. Mikels (1992) reported the turbidity of pumped water from the collector well of Kalama, Washington to range from 0.3 to 0.4 nephelometric turbidity unit (NTU) and during same time the Columbia River turbidity varied between 1 and 5 NTU [32].

From Table 6, it was clear that the removal of color was quite high (73.56%) during the third sampling hour which is on 0300 HRS, 28/9/13. The true color reading were found to be 70 TCU in the PW and 109 TCU in the RW. The removal of color was lowest on 29/9/13 at 0300 HRS where the removal was able to reach only 35.78% for the whole pumping test programme. From the water quality results, it can be seen that the color removal shows some increment at the early stage of the pumping test and slowly decreased in the middle of the pumping test before the removal reached 50%. Then the color removal was seen to decrease again to only 38.46% till the end of the pumping test.

Table 7 shows that, from the first day to the end of pumping test, the iron concentration for the river water was seen to increase slightly from 0.59 mg/l to 19 mg/l. After 48 hours, the iron concentration for river water decreased to 4.2 mg/l. The iron concentration was found to show some gradual increasing and decreasing pattern. Throughout the three-day of pumping test, the iron concentration was constantly same for the first 24 hours but then iron concentration decrease drastically to 0.99 mg/l. The percentage removal for iron was highest during the second day of the pumping test, where the removal of iron was up to almost 87.93%. The concentration of iron in bank filtrate is less due to some oxidation– reduction reactions. In such redox reactions, iron oxides are mobilized under reduced conditions whereas these oxides are adsorbed and precipitated under oxidized conditions. In general, the iron concentration is low in water. In igneous rock, iron is present in pyroxenes, amphiboles, biotite, magnetite, and nesosilicate olivine [33]. While Fe^{3+} in the alluvium in the study area was produced in reduction state, the higher Fe^{3+} concentration in the river water than in the PW indicated anthropogenic contamination along the overland flow and runoff.

Table 7 shows that at the first sampling hours of *E.coli*, the results of water quality analyses of pumping test shows that the presence of *E.coli* was less than 1 for both the RW and PW. The multiple probable number (MPN) results shows acceptable amount of *E.coli* in the river water while less than one or zero results of MPN were recorded throughout the 72 hours of pumping test programme. The removal of *E.coli* in this pumping test was very effective due to the filtration process of the bank. Water quality analyses result shows that bank filtration were able to remove *E.coli* for almost 100% undoubtedly, thus makes it safe for human consumption. Removal of microorganisms during soil passage mainly occurs through the inactivation, adsorption, staining and sedimentation processes and is controlled by the temperature, rainfall, nature of the soil and the type of microbe present [34,35,36,37]. River water level and groundwater level fluctuations, however, may also lead to remobilization of deposited colloids, including virus particles [38]. Wang *et al*. (1995) observed particle removal up to 2.4 log units from the Ohio River water [39].

The quality of RBF filtered water depends on several factors: surface water quality, local geology, distance of the wells from the surface water, RBF intake amount, biogeochemical processes, land use, and climate condition [40]. Elimination of microbial organisms and turbidity in RBF occurs through biodegradation, natural filtration, sorption and dilution of ground water [41]. Besides, some other factors such as pH, ionic strength, redox conditions in groundwater, travel time in the bank, temperature, pore water velocity and soil properties, are also involved in coliform removal [42]. However, the quality of water is affected dominantly by the strata through which water travels. Purification during bank filtration mainly depends on environmental conditions, location at bank, well design, well operation, travel time, runoff regime, and river water and ground water qualities [43,44]. The porous media behaves as a natural filter and also biochemically attenuates potential contaminants present in the river water.

4.0 CONCLUSION

Riverbank filtration is a promising technology that helps improving water quality parameters such as turbidity, color, iron, and *E.coli*. The removal percentage for turbidity was up to 98.78% while the color and iron were removed to 73.56% and 87.93% each, respectively. The removal for E.*coli* was found to be almost 100% for all sampling time during the pumping test programme. The results for water quality test indicates that Kuala Kangsar site is suitable for source abstraction for protection of future water security.

Acknowledgement

The authors would like to acknowledge the Ministry of Education Malaysia for providing financial support through LRGS Grant on Water Security entitled Protection of Drinking Water: Source Abstraction and Treatment (203/PKT/6720006).

References

[1] Tufenkji, N., Ryan, J. N. and Elimelech, M. 2002. The Promise of Bank Filtration. *Environmental Science and Technology*. 36(21): 422A-428A.

[2] Schubert, J. 2002a. Hydraulic Aspects of Riverbank Filtration–Field Studies. *Journal of Hydrology*. 266: 145-161.

[3] Ray, C., Melin, G., Linsky, R. B. 2002. *Riverbank Filtration Improving Source-Water Quality*. Kluwer, Dordrecht, The Netherlands.

[4] Sandhu, C., Grischek, T., Kumar, P. and Ray, C. 2010. Potential for Riverbank Filtration in India. *Clean Techn Environ Policy*. 1-22 (DOI 10.1007/s10098-010-0298-0).

[5] Ray, C. 2008. Worldwide Potential of Riverbank Filtration. *Clean Technologies and Environmental Policy*. 10: 223-225.

[6] Sontheimer, H. 1980. *J. AWWA*. 72(7): 386-390.

[7] Dash, R. R., Mehrotra, I., Kumar, P., Grischek, T. 2008. Lake Bank Filtration at Nainital, India: Water Quality Evaluation. *Hydrogeol J*. 16(6):1089-1099.

[8] Dillon, P. J., Miller, M., Fallowfield, H., Hutson, J. 2002. The Potential of River Bank Filtration for Drinking Water Supplies in Relation to Microcystin Removal in Brackish Aquifers. *JHydrol.* 266(3): 209-22.

[9] Wang, J., Smith, J., Dooleym L. 1995. Evaluation of Riverbank Infiltration as a Process for Removing Particles and DBP Precursors. In: *Proceedings Water Quality Technology Conf, American Water Works Assoc., Denver, CO.*

[10] Massmann, G., Tichomirowa, M., Merz, C., Pekdeger, A. 2003. Sulfide Oxidation and Sulfate Reduction in a Shallow Groundwater System (Oderbruch Aquifer, Germany). *J Hydrol*. 278(1): 231-243.

[11] Ray, C., Grischek, T., Schubert, J., Wang, J. Z. and Speth, T. F. 2002. A Perspective of Riverbank Filtration. *Journal of American Water Works Association (AWWA)*. 94 (4): 149-160.

[12] Verstraeten, I. M., Thurman, E. M., Lindsey, M. E., Lee, E. C., Smith, R. D. 2002. Changes in Concentrations of Triazine and Acetamide Herbicides by Bank Filtration, Ozonation, and Chlorination in aA Public Water Supply. *J Hydrol.* 266(3-4):190-208.

[13] Wang, J., Smith, J., Dooley, L. 1995. Evaluation of Riverbank Infiltration as a Process for Removing Particles and DBP Precursors. In: *Proceedings Water Quality Technology Conf, American Water Works Assoc., Denver, CO.*

[14] Kühn, W., Müller, U. 2000. Riverbank Filtration: An Overview. *J AWWA*. 92(12): 60-69.

[15] Ray, C., Grischek, T., Hunt, H. 2004. An Introduction to Riverbank Filtration Potential for Drinking Water Production. In: *Proceedings ofWorkshop.*

[16] Doussan, C., Poitevin, G., Ledoux, E., Detay, M. 1997. River Bank Filtration: Modeling of the Changes in Water Chemistry with Emphasis on Nitrogen Species. *J Contam Hydrol.* 25(1-2): 129-1561.

[17] Miettinen, I. T., Martikainen, P. J., Vartiainen, T. 1994. Humus Trans-formation at the Bank Filtration Water Plant. *Water Sci Technol.* 30(10):179-187.

[18] Worch, E., Grischek, T., Börnick, H., Eppinger, P. 2002. Laboratory Tests for Simulating Attenuation Processes of Aromatic Amines In Riverbank Filtration. *J Hydrol.* 266(3-4): 259-268.

[19] Weiss, W. J., Bouwer, E. J., Ball, W. P., O'Melia, C. R., Arora, H., Speth, T. F. 2003. Riverbank Filtration: Fate of DBP Precursors and Selected Microorganisms. *J AWWA*. 95(10): 68-81.

[20] Weiss, W. J., Bouwer, E. J., Ball, W. P., O'Melia, C. R., Arora, H., Speth, T. F. 2002. Reduction in Disinfection by Product Precursors and Pathogens During Riverbank Filtration at Three Midwestern United States Drinking-Water Utilities. In: Ray C Et Al (Eds) Riverbank Filtration: Improving Source Water Quality. Kluwer, Dordrecht, The Netherlands. 147-174.

[21] Gollnitz, W. D., Clancy, J. L., Whitteberry, B. L., Vogt, J. A. 2003. RBF as a Microbial Treatment Process. *J AWWA*. 95(12): 56-66.

[22] Tufenkji, N., Ryan, J. N., Elimelech, M. 2002. Bank Filtration. *Environ Sci Technol.* 36(21): 422A-428A.

[23] Medema, G. J., Juhasz-Holterman, M. H. A., Luijten, J. A. 2000. Removal of Micro-organisms by Bank Filtration in a Gravel-Sand Soil. In: Jülich W, Schubert J (eds) Proceedings Int Riverbank Filtration Conf., International Association of the Rhine Waterworks (IAWR), Amsterdam. 161-168.

[25] Price, M. L., Flugum, J., Jeane, P., Tribbet-Peelen, L. 1999. Sonoma County Finds Groundwater Under Direct Influence of Surface Water Depends on River Conditions. In: *Proceedings Int. Riverbank Filtration Conf., National Water Research Institute, Fountain Valley, CA.* 25-27.

[26] Havelaar, A. H., van Olphen, M., Schijven, J. F. 1995. Removal and Inactivation of Viruses by Drinking Water Treatment Processes Under Full-Scale Conditions. *Water Sci Techno*l. 31(5-6): 55-62.

[27] Shamrukh, M., Abdel-Wahab, A. 2008. Riverbank Filtration for Sustainable Water Supply: Application to a Large-scale Facility on the Nile River. *Clean Technol Environ Policy*. 10: 351–358. doi:10.1007/s10098-007-0143-2.

[28] Wang, J., Smith, J., Dooley, L. 1995. Evaluation of Riverbank Infiltration as a Process for Removing Particles and DBP Precursors. In: Proceedings Water Quality Technology Conf, American Water Works Assoc., Denver, CO.

[29] Mikels, M. S. 1992. Characterizing the Influence of Surface Water on Water Produced by Collector Wells. *J. AWWA*. 84(9): 77-84.

[30] Havelaar, A. H., van Olphen, M., Schijven, J. F. 1995. Removal and Inactivation of Viruses by Drinking Water Treatment Processes Under Full-Scale Conditions. *Water Sci Technol.* 31(5-6): 55-62.

[31] Schubert, J. 2006. Significance of Hydrologic Aspects on RBF Performance. In:Hubbs, S. (Ed.), Riverbank Filtration Hydrology. 17-41.

[32] Shankar, V., Eckert, P., Ojha, C., König, C. 2009. Transient Three-dimensional Modeling of Riverbank Filtration at

Grind Well Field, Germany. *Hydrogeology Journal*. 17: 321-326.

[33] Hem, J. D. 1985. Study and Interpretation of the Chemical Characteristics of Natural Water. US Geological Survey Water-Supply Paper 2254. 263

[34] Yates, M. V., Gerba, C. P. and Kelley, L. M. 1985. Virus Persistence in Groundwater. *Appl. Environ. Microbiol.* 49: 778-781.

[35] Schijven, J. F., Berger, P. and Miettinen, I. 2002. Removal of Pathogens, Surrogates, Indicators, and Toxins Using Riverbank Filtration. In Riverbank Filtration Improving Source–Water Quality (eds Ray, C., Melin, G. and Linsky, R. B.), Kluwer Academic Publishers, Dordrecht. 73-116.

[36] Aronino, R., Dlugy, C., Arkhangelsky, E., Shandalov, S., Oron, G., Brenner, A. and Gitis, V. 2009. Removal of Viruses from Surface Water and Secondary Effluents by Sand Filtration. *Water Res.* 43: 87-96.

[37] De Roda Husman, A. M., Lodder, W. J., Rutjes, S. A., Schijven, J. F. and Teunis, P. F. M. 2009. Long-term Inactivation Study of Three Enteroviruses in Artificial Surface And Groundwaters using PCR and Cell Culture. *Appl. Environ. Microbiol*. 75: 1050-1057.

[38] Torkzaban, S., Hassanizadeh, S., Schijven, J., van den Berg, H. 2006. Role of Air–water Interfaces on the Retention of Viruses Under Unsaturated Conditions. *Water Resources Research*. 42: 1-11.

[39] Ray, C., Melin, G., Linsky, R. B., 2002a. Riverbank Filtration: Improving Source-water Quality. Kluwer Academic Publishers, Fountain Valley, CA, USA. 364. Ray, C., Soong, T. W., Lian, Y. Q., Roadcap, G. 2002b. Effect of Flood-induced Chemical Load on Filtrate Quality at Bank Filtration Sites. *Journal of Hydrology*. 266: 235-258

[40] Cady, P. 2011. A Riverbank Filtration Demonstration Project on the Kali River. Master's Thesis. University of Rhode Island, Dandeli, Karnataka, India. 66.

[41] Shamrukh, M. and Abdel-Wahab, A. 2008. Riverbank Filtration for Sustainable Water Supply: Application to a Large-Scale Facility on the Nile River. *Clean Technol. Environ Policy.* 10: 351-358.

[42] Hiscock, K. M. and Grischek, T. 2002. Attenuation of Groundwater Pollution by Bank Filtration. *J. Hydrol*. 266: 139-144.

[43] Kuehn, W. and Mueller, U. 2002. Riverbank Filtration: An Overview. *J. Am. Water Works Assoc*. 92: 60-69.