Removal of *E.Coli* and Turbidity Using Riverbank Filtration Technique (RBF) for Riverside Alluvial Soil in Malaysia

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ABSTRACT

Riverbank filtration (RBF) is an efficient and low-cost natural alternative filtration technology for water supply application. In this method, the surface water contaminants are removed or degraded as the infiltrating water moves from the river to the abstraction wells. As the induced surface water filters through the riverbed sediments and aquifer materials, most suspended and dissolved contaminants, including pathogenic bacteria and viruses are filtered out. It has been applied for more than 100 years in Europe and the United States to provide drinking water to the communities. However, this technology is new and not well explored in Malaysia. In order to understand and develop further knowledge on RBF, USM research team has embarked on the study of RBF at different locations in Malaysia. Three pilot projects of RBF facilities were constructed in the states of Selangor, Perak and Kedah. The aim of this study was to analyze the quality of bank-filtered water in terms of turbidity and E.Coli removal from the studied areas. During the study, riverbank-filtered water and river water samples were collected during pumping test and analyzed in the field and at the laboratory. Turbidity in the range of 15.6-260 NTU in river water was reduced to 0.01-12.5 NTU in pumping well for all sites. The removal for E.Coli was found to be almost 100% for all sampling time during the pumping test programme.

INTRODUCTION

The growing need for clean drinking water has increased the interest worldwide and it is one of the most pressing global environmental and health problems of our time. The issue of drinking water supply is addressed around the world with different treatment technologies. As the demand for piped drinking water is increasing in developing economies, water utilities are facing the challenge of treating surface water that is often polluted. Water utilities have developed new technologies for treating waters of degraded quality, such as membrane filtration, soil-aquifer treatment, and advanced oxidation. The goal of all water treatment technologies is to remove turbidity as well as chemical and pathogenic contaminants from water sources in the most affordable and expedient manner possible. One possibility of growing interest to water utilities is the technology of riverbank filtration (RBF).

The RBF, a type of indirect artificial recharge, occurs through a process whereby river water passes through alluvium near a river. The water will be extracted from wells adjacent to a river or from horizontal collector wells beneath a river bed or within the banks in order to induce infiltration from the river [1]. It is an efficient and low-cost natural alternative technology for water supply application in which surface water contaminants are removed or degraded as the infiltrating water moves from the river to the pumping wells [2]. As the induced surface water filters through the riverbed sediments and aquifer materials, most suspended and dissolved contaminants, including pathogenic bacteria and viruses are filtered out [3]. Thus, the quality of drinking water can be improved by using RBF compared to directly purified river water [4]. Though this is a simple, passive way of pre-treating water, numerous studies have been done by scientists to understand the complex geological, biological and hydraulic factors that control contaminant removal trough RBF.

During the RBF process, physical and biochemical processes such as dilution, sorption, ion exchange, natural attenuation by microorganisms, filtering, and other chemical reactions can enhance groundwater quality by reducing physical materials (turbidity and microscopic particles), chemical components (dissolved organic carbon, pesticides, synthetic organics, pharmaceutical compounds, nitrate, dissolved ions, and metals), and biological contaminants such as protozoa, bacteria, and viruses [5]. Experiences from bank filtration investigations demonstrated that it is a highly effective method for significant removal of turbidity [6,7,8], natural organic matter [9], trace organic chemicals [10,11], pesticides, and pharmaceuticals [12,13,14,15,16,17,18,19], salinity [20,21], as well as taste- and odor-causing compounds, which may not be removed from the surface water by conventional treatment methods [22,23]. Shamrukh, *et al*., [24] compared the physical, chemical, and microbiological qualities of RBW with river water and background natural groundwater in a Nile valley region of Upper Egypt. They demonstrated that the RBW qualities were superior to those of the other waters, especially in term of turbidity, total coliform, and *Escherichia coli*. The ability of bank filtration schemes to provide a significant barrier to microorganisms has also been observed [17,25,26,27,28,29,30,31,32] 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 [26,33,34,35]. Dash, *et al*., [6] reported that bank filtrate abstracted from a production well on Pant Dweep Island, when compared with Ganga River water, showed 2.5 log removal of total coliforms, 3.5 log removal of fecal coliforms, 0.7 log removal of turbidity in the non-monsoon period (November 2005–June 2006) for the rapid travel times of 84–126 days for a distance of 115 m to the New Supply Channel (NSC), and 4.7 log removal of total coliforms, 4.4 log removal of fecal coliforms, 2.5 log removal of turbidity, and 1.0 log removal for organics in terms of UV absorbance during the monsoon period (July–September 2006) for the travel times of 77–126 days. Ali, *et al.,* [2] investigated the new facility of RBF in new Aswan city, at the western bank of the Nile River. The physicochemical and microbial measurements have proven the effectiveness of RBF system in the study area. Monitored values of the physicochemical water quality measurements were turbidity, DO, TSS, TOC, NO_2, Mn, PO_4, and Fe, using the RBF system, were showing significant results. The riverbank filtrate technique reduced and nearly removed more than 95% of the total bacteria and total coliform bacteria from the RBF systems.

As shown in previous studies, the positive attributes in many aspects of RBF suggest that this system is a very appealing method that can be implemented in tropical countries such as Malaysia. Even though the country receives abundant rainfall throughout the year, most of the urban rivers are polluted [36], and the use of groundwater as a public water supply is very limited. These factors impose pressure in terms of treatment cost and increased demand to existing water-treatment plants, which have prompted water-resource agencies to look for alternative supplementary sources. However, detailed published works that reported on the successful implementation of the RBF system in the tropical region remain few 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. In order to understand and to develop further knowledge on RBF, USM research team has embarked on the study of RBF at different locations in Malaysia. Three pilot projects of RBF facilities were constructed in the states of Selangor, Perak and Kedah. The aim of this study was to analyze the quality of bank-filtered water in terms of turbidity and *E. Coli* removal from the studied areas.

MATERIALS AND METHODS

A. Study Areas

In order to determine whether bank filtration will be a beneficial component of the water supply scheme in Malaysia, a thorough site investigation of the target site is required. Three pilot projects had been established in Malaysia in the state of Selangor, Perak and Kedah. The study areas had been chosen due to their pollution level of surface water, location and soil characteristics. In the state of Selangor the study site was located at Jenderam Hilir, Dengkil in the southwest state of Selangor within the Langat Basin. It is located between latitude 2°53′ 28.56″N to 2° 53′ 39.75″ and longitude 101° 42′ 03.78″E to 101° 44′ 14.58″E. It is approximately 4km to the south of raw water intake of SYABAS water treatment plant. The Langat river basin is an important water supply source in the Klang Valley and was classified as River of Class I and II. While in Perak state, Kuala Kangsar was selected for RBF application after considering the soil profile near the Sungai Perak. The study area was located near to water intake for water treatment plant of Perak Water Board in Kampung Kota Lama Kiri, Kuala Kangsar Perak with latitude and longitude 04°48’08.5’’N and 100°57’06.9’’E. Sungai Perak has been classified as River of Class II. The study site in the state of Kedah was located Lubuk Buntar, Kedah Darul Aman. It is located at longitude and latitude of 5° 7'37.60"N and 100°35'42.97"E. The area was close 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 at the border between Kedah and Perak and it was classified as River of Class II and III.

B. Aquifer Information

The study site which was located in Selangor which consists of alluvial deposits of sand, silt, and gravel, which form a shallow confined aquifer. The overlying layer consists of clay, with thickness of about 1–3m in places. The aquifer is mostly composed of fine-to-coarse-grained sand with a mixture of gravel. The thickness of the aquifer ranges from 5 to 20m, and it can be locally heterogeneous because of the presence of beds of fine-to-coarse-grained sand. It was considered that the thickness of the aquifer was about 15m. Based on the drilling information, gravelly sand or sandy gravel aquifer layers are overlain by the layer of clay, which make the aquifer confined or semi-confined depending on the location. The bedrock in the study area is located at a depth of 20m [37]. Based on the pumping test results, the test well (PW) was capable of producing 142.21m^3/hour of water (3.413 MLD) with the drawdown 2.17m. The transmissivity value (T) and hydraulic conductivity value (K) was 59.15m^2/hour and 4.41m/hour (105.84m/day) respectively [38]. Aquifer of the study site in Perak consists of medium sand, fine sand, coarse sand and gravel. The grain size distributions for PW indicate that down to a depth of 8m, the soils have a high percentage of medium sand, fine sand, coarse sand and gravel; and more gravel beyond the 8m depth, thus making it suitable for the purpose of a pumping well. There was no silt or clay found in the soil samples of all boreholes. Nevertheless, the main aquifer was considered to reside above the 8m mark due to the general presence of bedrocks at 8m. Result from the pumping test shown that the test well has yielded at a constant discharge rate of 112.10m^3/h with a drawdown of 0.79m. Based on the drilling information, the study area in Kedah consists of a layer of stiff clay at the top with a thickness ranging from ground level to 5m depth. The next layer is consisting of white sandy clay with thickness ranging from 5m to 16m depth. The layer ranging from 16m to 31m depth consists of coarse sand to gravel. The bedrock of this study area was found at a depth of 33m. From the investigation 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 16m to 33m 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. For Constant Discharge Test, the hydraulic conductivity and transmissivity were 7.86m/d and 133.57m^2/d, respectively. The overall rate for the production of test well was 0.737 MLD with a drawdown of 3.79m below ground level.

C. Water Sampling and Water Quality Analysis

A pumping test program was conducted at each site. For the study of water quality, water samples from the test well and river water were collected during the pumping test duration. The samplings were carried out at Kuala Kangsar site at 12, 24, 36, 48, 60 and 72 hours intervals during the pumping test. Meanwhile water samples were taken at Dengkil and Lubuk Buntar site at 8, 16, 24, 32, 40, 48, 56, 64 and 72 hours time intervals. Samples from river were collected at varying depths of 1.5m to 3m while samples from the test well (PW) were collected via the tap that has been installed at the riser pipe. The samples were collected in a clean polyethylene bottles. Turbidity was done in accordance to Standard Method 2130B using Turbiditimeter and *E.Coli* (IDEXX Colilert ® Test Method). *E.Coli* was enumerated using the Quanti-Tray enumeration procedure. Other parameters that have been analyzed were salinity, pH, temperature, conductivity, dissolved oxygen, iron and manganese. The parameters were tested using YSI Proplus meter and DR2800 Spectrophotometer. All tests were conducted on site during the constant discharge rate tests. The sampling method and analysis were in accordance to APHA 2005.

RESULTS AND DISCUSSION

A. Water Quality Analyses

Significant parameters of water quality at the three locations of RBF study site were obtained. Water quality analyses at two sampling locations were carried out. Those locations were the pumping water from the test well (PW) and from river water. Important water quality parameters of the abstraction water at the study site are listed in Table 1. Typical surface water parameters of concern include: total dissolved solids (TDS), pH, dissolved oxygen (DO), Electrical conductivity (EC), iron (Fe), manganese (Mn), turbidity and *E.Coli* for the monitoring period during the pumping test. From Table1 it shows the range of pH for Langat River, Kerian River and Perak River were 6.1-6.75, 5.18-5.79 and 6.15-6.75, respectively. However, pH values decreased in the test well for all sites and the readings were not complying with Malaysia Drinking Water Standard (2010). In terms of dissolved oxygen, the readings were reduced in the range of 1.5-3.6mg/l (Langat River), 3.7-6.0mg/l (Kerian River), 4.65-6.69mg/l (Perak River) to the range of 0.6-3.2mg/l (Jenderam Hilir), 3.1-4.4mg/l (Lubuk Buntar), and 1.17-3.32 (Kuala Kangsar) in the test wells for all sites. The dissolved oxygen content of water is influenced by the chemical or biological processes taking place in the distribution system. Results of iron are higher for water samples in the test wells (PW) and also exceeded the permissible limit of the Malaysian Drinking Water Standard. The limit for Fe was only 0.3mg/l. The Fe concentration in the wells ranged from 0.43-9.9mg/l, while in the river water, it ranged from 0.06 to 8.2mg/l. Grischeck, *et al.,* [39] studied that water quality change depends mainly on the redox reactions. These reactions were involving oxidized inorganic species such as Fe (III) and nitrate. Reduced organic carbon can strongly influence the levels of both organics and Fe (II) in groundwater. The manganese values are relatively low. As observed from Table 1 the concentration of Mn in river water at the three sites (vary from 0.1 to 9.1mg/l) is greater than riverbank filtrates (ranging from 0.09 to 3.9mg/l) at test wells. Manganese values agreed well with the main aim of applying the RBF system.

B. Removal of Turbidity

Particles measured as turbidity is a typical general water quality parameter for most surface waters and is a useful measurement tool for water quality analyses.

Although turbidity is not an inherent property of water, as is temperature or pH, it is recognized that turbidity is an indicator of the environmental health of water bodies [40]. Results from Table 1 shows that water samples from the river have high turbidity which exceeds the Malaysia Drinking Water Standard (2010) which is 5 NTU. Turbidity of Kerian River shows the highest reading among the three sites. It varies between 260-120 NTU in the river water, where in riverbank filtrates at test well it ranges from 0.32-12.3 NTU. Figure 1 shows percentage removal of turbidity. As observed from the figure, percentage removal of turbidity was in the range of 92.63% to 99.87%. Turbidity in drinking water is caused by the 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 [2]. Samples of river water from Langat River and Kuala Kangsar had turbidity in the range of 24.43-80.9 NTU and 15.6-21.4 NTU. The turbidity was reduced to the range of 0.01-9.32 NTU and 0.19-1.19 NTU with percentage removals of 81.79%-99.79% and 71.34%-97.49%, respectively. As the river water passes through the aquifer, most contaminants are attenuated and diluted. Therefore, most of the turbidity and organic pollutants can be removed by the bankside material and diluted with groundwater [37].

Table 1: Water quality at RBF wells investigated and the opposite sampling points in the rivers

Parameter	Water Quality During Pumping Test					
	Jenderam Hilir		Kuala Kangsar		Lubuk Buntar	
	Langat River	Test Well (PW)	Perak River	Test Well (PW)	Kerian River	Test Well (PW)
TEMPERATURE, °C	29.1-30.2	28-28.2	28-29.7	28-28.7	26.9-28.2	25.4-27.9
pH	6.1-6.75	5.39-5.7	6.15-6.75	5.32-5.94	5.18-5.79	5.1-5.5
SALINITY, (ppt)	0.12-0.14	0.08-0.1	0.02-0.03	0.09	0.02-0.04	0.0-0.04
DO, (mg/L)	1.5-3.6	0.6-3.2	4.65-6.69	1.17-3.32	3.7-6.0	3.1-4.4
TDS, (mg/L)	176-192	108-130	33.2-43.9	120-129	31.2-62.4	41.0-56.5
E. COND. (uS/cm)	295-324	126-213	54.9-71.6	195-211	50.0-101.3	66.2-1.2
IRON, Fe (mg/l)	0.06-0.09	0.43-1.7	0.59-19	7.9-9.9	0.14-1.94	0.44-5.1
MANGANESE, Mn (g/l)	0.1-4.6	0.09-1.9	2.8-5.7	1.0-12	2.6-9.1	1.5-3.9
TURBIDITY, NTU	24.43-80.9	0.01-.32	15.6-21.4	0.19-1.19	260-120	0.32-12.3
E.COLI, MPN	488.4-2419.6	0	344.8-727	>1-1	435.2-32.9	<0-2

C. Removal of *E.Coli*

The most common and widespread health risk associated with drinking water is the microbiological contamination, either directly or indirectly. Coliforms are a family of bacteria common in soils, plants, and animals. It can also be found in water contaminated by domestic sewage or other sources of human and animal waste. It can survive and grow in water distribution systems [2,41,42]. Microbial measurement for pathogens was carried out for the collected water samples during pumping test at the three RBF pilot sites to analyze the presence of microorganisms. Results from Table 1 show that water samples that were taken from the rivers were positive for *E.Coli*. Langat River and Kerian River showed high range of *E.Coli* compared to Perak River. The multiple probable number (MPN) results showed acceptable amount of *E.Coli* in the river water while less than one or nil were recorded throughout the 72 hours of pumping test programme. Figure 2 shows removal percentage of *E.Coli*. The removal of *E.Coli* in this pumping test was very effective due to the filtration process of the bank. As observed from Figure 2, water quality analyses results show that bank filtration were able to remove *E.Coli* to almost 100%. Thus, this result is compatible with the main aim of RBF system. Removal of microorganisms during soil passage mainly occurs through the inactivation, adsorption, straining and sedimentation processes and is controlled by the temperature, rainfall, nature of the soil and the types of microbes present [43].

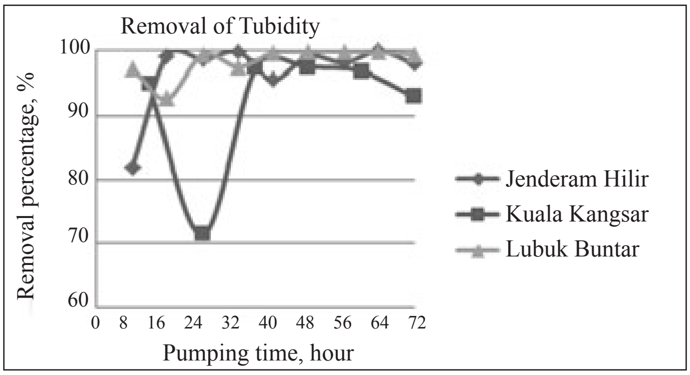

Figure 1: Percentage Removal of Turbidity

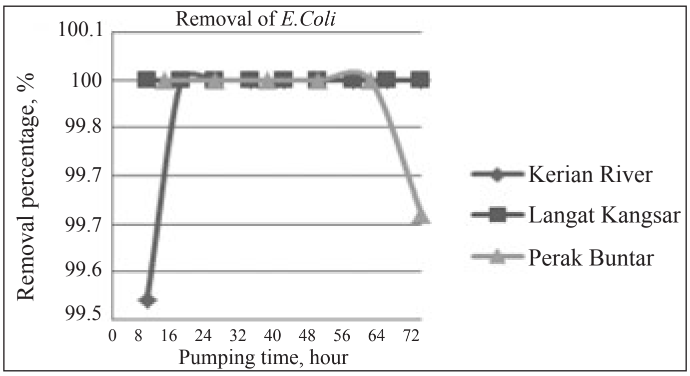

Figure 2: Percentage Removal of E.Coli

IV. CONCLUSION

Riverbank filtration is a promising technology that helps improve water quality parameters such as turbidity, color, and *E.Coli*. In order to study the effect of RBF, significant parameters of water quality at three locations of RBF pilot project site were obtained and monitored during 72 hours of pumping test program. From these results, it clearly shows that RBF is capable of reducimg turbidity and *E.Coli*. The removal percentage for turbidity was up to 99.79%. The removal of *E.Coli* was found to be almost 100% for all samples during the pumping test program. Results that were achieved in this study show that horizontal-flow filtration using the RBF system may be considered as a low cost and total treatment system, in which treated water exited from the filter may be sent to distribution network after simple post chlorination. The results for water quality test indicated that the three (3) pilot projects of RBF facilities are suitable for source abstraction for a reliable water supply and would provide a significant protection for water security in the future.

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