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Chapter

Application of Artificial Barrier as Mitigation of *E. coli* Which Pass through Riverbank Filtration

Nur Aziemah Abd Rashid and Ismail Abustan

Abstract

Water security in the water treatment plant has been doubted, and the treatment process may have given unreliable and unsafe water to the public. A newspaper reported on November 19, 2011, that laboratory tests on water samples in Kelantan for each year by the Ministry of Health have found harmful bacteria including *Escherichia coli* (*E. coli*) in the water samples. More worryingly, it was stated in a study that chlorine in water treated with high chlorine can be harmful to human health. In 2010, Malaysia has begun to approach a natural treatment technique, namely, riverbank filtration (RBF), and firstly used it at the Water Treatment Plant in Jeli, Kelantan, and Kuala Kangsar, Perak. RBF limitation is the invisible groundwater flow that makes it difficult to predict the transport of contaminants. Managing groundwater is important to ensure that water is aligned in compliance with government legislation and environmental protection. Due to that, this study suggests an implementation of an artificial barrier for microorganism in RBF to sustain the good water quality abstracted from the abstraction well. This pretreatment or purifying method is to improve the effectiveness of RBF in removing pollutants during shock loads and reduce the load placed in the water treatment process.

Keywords: artificial barrier, riverbank filtration, *E. coli*, groundwater, water security

1. Introduction

Potable water access globally is now under crisis, which leads to poor human health issue, affecting Malaysia as one of the countries facing this problem. The main reasons why this happens are due to climate change, deterioration of river water quality, unreliable water treatment system, and increase of population, which, at the same time, causes water shortage to occur. During dry weather conditions, further depletion of water occurs. Pertinently, climate changes make the drought season becomes longer and hotter than usual. The dam water becomes low and the river water dries up. The deterioration of river water quality in Malaysia has brought an impact to the water treatment plant due to the increase of treatment cost and maintenance. Chemicals such as PACI, alum, and others will also be increased to treat the polluted river. In the year of 2011, it was stated in a study that chlorine in water treated with high chlorine can be harmful to human health [1]. Thus, water security in the water treatment plant has been doubted, and the treatment process may have given unreliable and unsafe water to the public. Recently, *Utusan Malaysia* newspaper reported on November 19, 2011, that laboratory tests on water samples in Kelantan for each year by the Ministry of Health have found heavy metals and harmful bacteria including *Escherichia coli* (*E. coli*) in the water samples. More worryingly, *E. coli* was also found in water supplied to homes by Air Kelantan Sdn. Bhd. (AKSB). The discovery of *E. coli* in water samples in Kelantan detected by the ministry was then carried out from 2008 to 2010.

Providing reliable and safe potable water has become a human right for us. Therefore, finding a solution to these issues is highly desirable to improve the safety and reliability of potable water. In 2010, Malaysia has begun to approach a new treatment technique, namely, riverbank filtration (RBF). RBF is a method using groundwater that is expected to provide a new way to increase water intake and untapped resources in Malaysia, firstly used at the Water Treatment Plant in Jeli, Kelantan, and Kuala Kangsar, Perak. RBF is a natural system in which it involves the entry of river water into underground aquifers and is caused by hydraulic gradients, whereby water retrieval is from collector wells located at banks, at a certain distance from the river [2]. Although it is still less than 10 years in Malaysia, RBF method shows good results to reduce the use of chemicals and produces biologically stable water; the system also improves water quality by removing particles (turbidity and suspended solids), organic pollutants, microorganisms, heavy metals, and nitrogen. One previous experience in Germany shows that RBF provides a strong barrier for various pollutants and can help to ease the temperature fluctuations and concentration peaks when it is associated with spills into rivers. It also replaces and supports other treatment processes and reduces the overall costs of water treatment plant [3]. The removal of sediment, organic and inorganic compounds, and pathogens takes place during the first meters from the river in what is known as the hyporheic zone, which usually presents reducing conditions, due to high microbial activity that consumes oxygen in the water. Within this zone, there are important biochemical processes and redox reactions that affect groundwater quality [4]. In general, every stage of RBF has an environmental influence that is from the river until abstraction well.

Safe potable water is one of the implicit requisites for a healthy human population. In the existence of RBF, artificial barrier is a new efficient purifying method to maintain safer water abstraction. This study demonstrates the potential of a new application of artificial barrier to filtrate *E. coli* in water in RBF system. The artificial barrier efficiency was examined for different media ratio. Artificial barrier is a man-made vertical barrier to pretreat water abstraction intake. It is a mixture of sand (local soil), granular activated carbon (GAC), and zeolite. Generally, the individual application of coconut shell GAC and zeolite has shown great advantages in terms of characteristics, adsorption capacities, as well as their physicochemical versatility. For that reason, the idea of combining the precursors in order to make an effective filter-based adsorbent for RBF purifying process is highly recommended. Besides that, the inherited limitation of an individual precursor in water treatment process could be minimized by combining them in layered filter adsorbent as first and second barriers in RBF aquifer due to low turbidity. GAC and zeolite have high permeability which make them suitable to be applied in RBF aquifer, which requires high permeability condition as for the RBF site. However, studies on the removal of *E. coli* from actual river water using artificial barrier (GAC and zeolite) in RBF as the pretreatment or purifying process are still limited until now. Similarly, studies concerning the optimization of adsorption treatment for the studied parameter removal from river water are inadequate. Due to that, this research study is mainly focused on the treatment of actual river water from Sungai Kerian, Lubok Buntar, Kedah, via artificial barrier fixed-bed flow studies.

2. Riverbank filtration

2.1 Principle and treatment

RBF has begun to be widely used in Malaysia as to optimize the water supply. The introduction of RBF in Malaysia is started in 2010 at Jeli, Kelantan. The plants' operation has demonstrated the success of the combination of RBF (as pretreatment) and water treatment plant (as posttreatment). Most RBF in Malaysia have been applied in Kelantan areas. After calculating all the costs (not including the cost of pumps, pipes, valves, etc.), 1 m^3 of drinking water costs approximately USD 0.04, which is considered to be a competitive price for the Malaysian. The combined method has therefore proved to be both technologically and financially viable. These findings should pave the way for other municipal authorities to follow suit by introducing their own combined RBF with ultrafiltration.

RBF post water treatment has been employed dating back to the nineteenth century. During RBF, river or lake water is extracted indirectly by drawing it through the subsurface prior to use as in **Figure 1**. The extraction is accomplished by an infiltration line of well either vertical or horizontal. The well is located at a short (below 30 m) to intermediate (up to 60 m) distance from the riverbank or lake. During extraction of water, the groundwater that discharges into the river decreases, and the groundwater table near the waterline may decrease below the river water level. To ensure a satisfactory purification, the distance between the river and the extraction well should such that the travel time exceeds 30–60 days [5].

During infiltration and travel through the soil and aquifer sediments, surface water is subjected to a combination of physical and chemical and biological processes of filtration. The top few centimeters of the riverbank materials formed are a screen or filter medium that removes the suspended solids present in the water. Heavy metal, phosphorous, and hydrophobic organic compounds present in the water are removed by adsorption onto certain aquifer materials. In the presence of biomass, the organic matter is further biodegraded (initially under oxic conditions and later under anoxic conditions). The water quality in most cases is improved by dilution of the surface water source with native groundwater [6]. When a particle becomes attached to the biofilm on the sand grain, microorganism may degrade that particle. There is an interception when particles are carried by one of the streamlines closest to the sand grain and a brushing effect occurs. There is general agreement that straining, adhesion, attachment, chemical adsorption, sedimentation, and biological growth all operate to some extent.

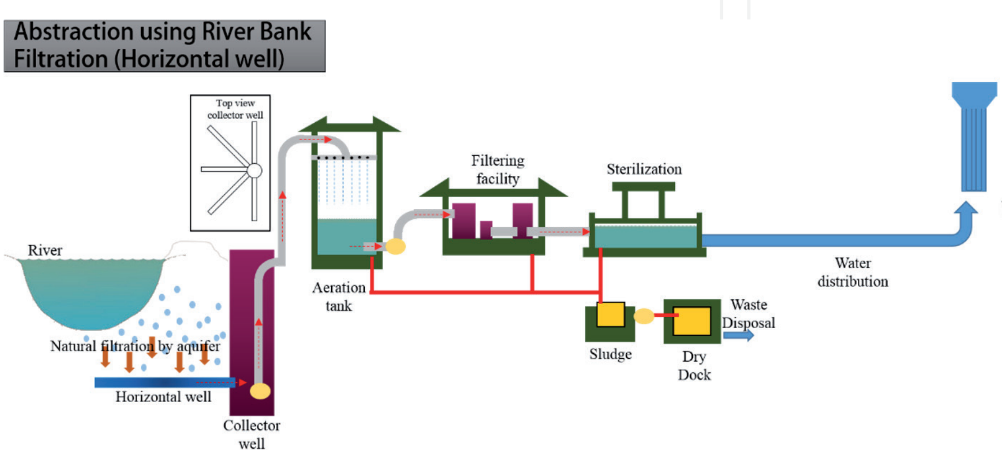

Figure 1.
Riverbank filtration system.

The conventional treatment commonly involves screening, aeration, coagulation, flocculation, sedimentation, slow sand filtration, and chlorination. The chemical treatment and waste product will increase if the pollutants in surface water increased. The RBF reduces the posttreatment step from six to only two steps which is removal of heavy metals (usually iron and manganese) by either aeration, activated carbon filter, or ultrafiltration and chlorination for taste and odor. This RBF system as a pretreatment technique applied in countries like the Netherlands, Germany, China, Korea, India, Egypt, and others has already succeeded in optimizing the potable water supply. The underground passage ensures the high quality of drinking water, which does not need any further treatment or disinfection before supply [7].

The posttreatment after RBF depends on the water abstraction water quality. Each RBF site has a different technique step for posttreatment. Previous study shows the most common pollutants that occur in RBF sites are iron and manganese. The treatments used to remove these contaminants in water are aeration, activated carbon filter, and ultrafiltration method. The second contaminant that occurs is taste and odor which are usually removed using chlorination. The third contaminant was microbiology which is solved by using ozonation and UV disinfection. This all posttreatment technique is commonly used at RBF site and summarized in **Table 1**. Meanwhile, there are RBF sites which are not using a posttreatment as a means for direct usage such as in China. However, in several years there will be oocyst problems.

2.2 Benefits and limitation

The RBF is a sustainable natural treatment process which avoids or reduces the use of chemicals and produces biologically stable water. The system improves water quality by removing particles (turbidity and suspended solid), organic pollutants,

Country	Treatment schemes	Comments
Netherland	Aeration, rapid sand filtration, activated carbon filtration and UV disinfection [8]	Electricity depends and less effective for low concentration of bacteria, virus, spores and cyst.
China	Direct usage	No iron problem. The most problem is with oocyst.
Malaysia	Cascading aerator, pressurized sand filter, ultrafiltration system [9]	Sudden increase of pollutants (cause of flood or natural disaster) may break down th ultrafiltration system and high maintenance of ultrafiltration system.
Germany	Ozonation, biological activated carbon filters, UV and safety chlorination (Small amount). [10]	The high levels of iron and manganese result to need of activated carbon filters. However, the activated carbon filters clogged. The piping get rust.
India	Aeration, filtration and chlorination. [11]	The usage of filtration as to filtrate the precipitation of iron and manganese in aeration section build a metal clogged filter. This may intribute to demenarilaziton during oxic condition.
Egypt	Aeration, filtration and chlorination [12]	-

Table 1.
Summary of RBF post treatment from other country and its limitations.

microorganism, heavy metals, and nitrogen. The RBF also helps to dampen the temperature fluctuations and concentration peaks when it is associated with spills into a river or lake. This treatment process also replaces and supports the other treatment processes by providing a robust barrier for multiple contaminants and reduces the overall cost of water treatment [3].

RBF limitation is the invisible groundwater flow that makes it difficult to predict the transport of contaminants. A specific concern of the RBF limitation is due to hydrology and dynamics of the river and groundwater, which have different climate variations (drought and rainy seasons), and thus, the groundwater level patterns result in significant fluctuation of contaminants in well stream loads. In rainy season, the rate of groundwater flow increases to a maximum level and causes small particles and pollutants to absorb into the soil where it encloses the flow along the groundwater flow, which initiates pollutants to enter the borehole. On the other hand, in dry season, minimum and ideal flow rates for pollutants are attached to the local soil. Moreover, since maximum groundwater flow rate occurs frequently in Malaysia, this incident is predicted to often result in significant fluctuations of underground hydraulic conductivity of groundwater and shock load of pollutants. Significant amount of pollutants may exist in borehole water due to high hydraulic conductivity and soil feature, which concludes that RBF is a natural treatment method that depends on natural behavior. In general, the quality of RBF water is influenced by the environmental conditions, where managing groundwater is important to ensure that water is aligned in compliance with government legislation and environmental protection.

The posttreatment step in most RBF sites is usually focused on iron and manganese treatment which result in the usage of aeration, activated carbon filter, and ultrafiltration treatment process. The weakness of this treatment which cannot be ignored has been discussed in the above section. The occurrence of the pollutants can be worse during shock load and clogging. Due to that, artificial barrier seems important which can increase the hydraulic conductivity of the underground water flow, reduce the pressure load to the aquifer during clogging, and enhance the pollutants adsorption during shock load. This can reduce the consumption of chemical treatment and strengthen the RBF barrier.

2.3 Factors influencing optimization of RBF

There are four basic important criteria affecting the performance of RBF which are hydrogeological conditions, source water quality and mixing with native groundwater, distance of the well from riverbank and spacing of wells and pumping rates, and sediment permeability. The effectiveness of RBF for removing surface water contaminants depends largely on hydrogeological conditions. It is about the soil microbiology, characteristic of the bank materials and streambed, and scouring characteristic [13]. In many countries, the alluvial soil aquifers hydraulically connected to a water course would be preferred sites for drinking water production [14]. The actual biochemical interactions that sustain the quality of the pumped bank filtration depend on numerous factors, including aquifer mineralogy and the extent of the aquifer [15].

The RBF shows a decreasing RBF water level with an increasing distance of the well apart from the riverbank. In addition to the decreasing RBF water level due to increasing distance, there is no cross flow of natural groundwater that the well could abstract river water [12]. Pumping test result shows that the water in well (below 60 m) comes from river water. However, the low-lying coastal aquifer is generally fragile and easily depleted due to anthropogenic activities and overexploitation of groundwater and agriculture. To manage and protect precious groundwater resources in a sustainable manner, the characterization and understanding of the natural evolution of groundwater chemistry are crucial to elucidate their geochemical nature and its relation.

The collector well can be far from the river if the soil type is sand and gravel such as RBF at Yellow River, China. The combination of vertical and horizontal collector well can maximize the water capacity such as RBF at Elbe River, Germany. However, clayey alluvial soil will limit the water capacity as RBF site at Lek River, Netherlands, shows the water capacity is only 0.01 MLD, compared to clayey alluvial soil at Nakdong River, Korea, which can be abstracted to 10 MLD water capacity. This shows clayey alluvial soil type needs deeper built collector well near the riverbank. The nearer to riverbank, the more water capacity can be abstracted than collector well at Nakdong River, Korea, which is only 10 MLD with 150 m distance from river, and collector well at Nile River, Egypt, with 22 MLD. Some sites do not contain gravelly sand alluvial soil type but can apply RBF such as Kali River, India. The highly pollutant river demands to use RBF methods; however, it only can abstract 0.8 MLD water capacity because the transmissivity of brownish red silty loam alluvial soil is low. Sites with clayey alluvial soil can apply limestone to increase the transmissivity of water such RBF sites at Ohio River, Kentucky, and Great Miami River, USA. Malaysia RBF sites at Sungai Semerak contain gravelly sand and shallow vertical well collector type. The shallow collector well nearer to riverbank helps RBF to avoid problem with iron and manganese. Thus, the RBF site that can supply huge water capacity is 25 MLD.

3. *Escherichia coli* in riverbank filtration

The abstracted water from RBF is very clear which has less contaminants than river water. According to previous study from other RBF sites, the contaminants that are below drinking water standard are turbidity, color, pH, TDS, chloride, ammonia, COD, BOD5, sulfate, iron, manganese, total coliform, and *E. coli*. RBF sites show great anthropogenic activity with the absence of total coliform and *E. coli* because the schmutzdecke (biofilm) layer exists at the bottom of the streamline [16] which can reduce the disinfection treatment. According to data obtained from the monitoring wells, the shallow geology of the RBF area is related to the alluvial deposition at the bottom of the streamline by the river which usually consists of upper fine, medium, and lower fine sand layers [17]. The quality of the ambient groundwater of the previous RBF sites at Louisville also shows that distance and location of the RBF wells from river are the key parameters of the RBF performance. If the RBF wells are very close to the river, then the problems of *E. coli* will be detected [18]. The existence of these enteropathogenic bacteria in abstracted well can be high in the range of 1–140 MPN/100 mL, respectively, as in **Table 2**.

Several of *E. coli* infection issues related to groundwater as drinking water were detected [19, 20] which the source of the infection was positively identified

Parameters	**References**				
	India [22]	China [23]	Egypt [24]	Brazil [16]	Netherland [25]
E. coli (MPN/100mL)	<140	<100	<1	Absence	10-103

***n/a = not available**

Table 2.
E. coli concentration during treated with RBF.

as a contaminated well or runoff from cow manure after torrential rain was thought to have been responsible for contamination [21]. As a safety precaution against *E. coli* infection in the body, the WHO fixed a 0.0 MPN/100 ml of *E. coli* for drinking water standard.

This study is focusing mainly on *E. coli* removal from groundwater. Typically the amount of *E. coli* depends on the aquifer types, distance of abstracted well to river, and climates. The removal of these parameters is crucial to ensure the treated groundwater can safely deliver to water treatment plant or directly distribute to consumer. *E. coli* is a Gram-negative, facultative anaerobic bacterium that belongs to the family of *Enterobacteriaceae*. *E. coli* is recognized as the most important parameter of fecal contaminants by microbiology and public health experts [26]. Depending on environmental conditions, *E. coli* can survive for 4–12 weeks [27]. There are various factors affecting the survival of *E. coli* in environment such as protozoa, antagonists, temperature, light, soil, pH, toxic substances, and oxygen [28]. The survival periods of *E. coli* in various surroundings were reported: in the groundwater at 10°C, recharged well and river water at 9–16°C, *E. coli* survived for 100 days, 63 days, and 55 days, respectively [29, 30]. Due to its strong relevance with the fecal contamination and relatively easy quantification methods, *E. coli* has been employed in a wide range of investigation including water treatment [31–33].

In natural conditions at RBF sites, water percolates through the organic soil where dissolved oxygen (DO) is consumed by the decomposition of organic matter and microbes in the soil. The decomposition process reduces the pH due to microbial action. When groundwater is pumped up to the surface, it gets into contact with air (O_2) which enters the solutions and starts the oxidation process that releases carbon dioxide (CO_2) from the groundwater to the atmosphere.

The reason for choosing *E. coli* as the main parameter is because it is a model for waterborne bacteria and reduces chemical usage in posttreatment. The *Escherichia coli* which is easily called as *E. coli* is a group of bacteria that are commonly found in food and water. Most of the *E. coli* is harmless, but some can cause sickness to human. These bacteria will lead to stomach and intestinal problems such as diarrhea and vomiting. The disease-causing *E. coli* strains live in the intestinal tracts of animals that ruminate, such as cows, deer, and goats. Bacteria early pretreatment seems important since it avoids to stimulate the bacterial growth in distribution system pipeline.

4. The possibility of *Escherichia coli* infection in riverbank filtration

The site was located at coordinates 5° 07′38.61" N and 100° 35'44.24", Lubok Buntar, Kedah. The examined site was influenced by the water from the Kerian River which was also influenced by the discharge of the wastewater from palm oil, mining industry, and poultry farming area at Sungai Mahang (upstream). The river water and borehole water samples were taken for laboratory (characteristics) test. **Figure 2** shows concentration plots of *E. coli* against height of water in tube well. It can be observed that the increase of height of water in tube well was caused by *E. coli* existence. The existing of *E. coli* was changed from absent to <200 MPN.

The depth of borehole was 30 m signifying that this borehole was under unconfined aquifer. The unconfined aquifer is recharged more rapidly when raining and groundwater hydraulic conductivity at maximum due to infiltration and runoff [34]. The increase of solute concentration during rainy season due to the groundwater flow exceeded the permeability of alluvial soil. Groundwater flow was maximized when raining which creates pressure to the alluvial soil. This leads small particle to flow together into abstraction well which in turn increases contaminant

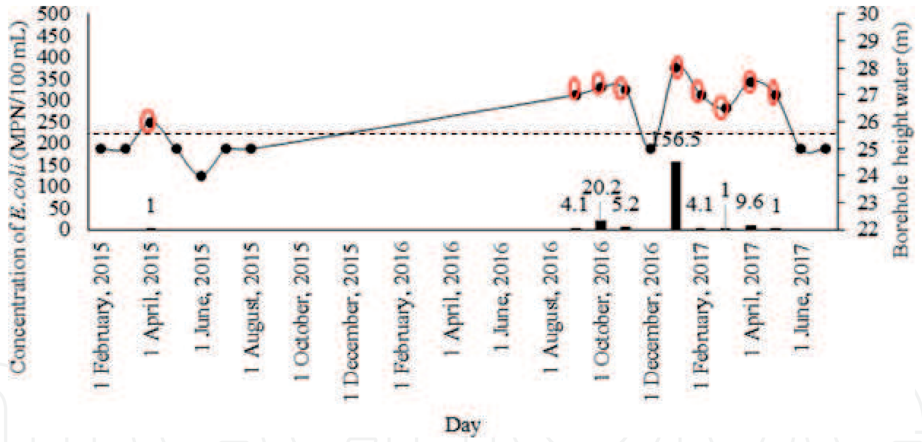

Figure 2.
The monitoring of E. coli concentration and height of borehole water for duration 2015–2017.

concentrations in abstraction water. For that reason, the application of artificial barrier seemed beneficial since it will increase the permeability of aquifer near the river avoiding small particles to flow together to abstraction well during rainy season. Besides raining, *E. coli* can penetrate into abstracted well due to pollution in streamline, abstracted well is near the riverbank, and sources of pollution such as poultry field and sanitary tank are close to abstracted well.

The experiment shows that the application of artificial barrier as RBF water purification method seems important to avoid the possibility of *E. coli* infection. Smith et al. [35] and Uhlmann et al. [36] previously identified exposure to drinking water from private underground water supply as a significant risk factor in human pathogen infections in the UK and Canada, respectively. In addition, O'Sullivan et al. [37] and Garvey et al. [38] have proposed that increases in *E. coli* infection in Ireland may be associated with water consumption from untreated water wells in rural areas, particularly following periods of excessive rainfall.

5. Artificial barrier for riverbank filtration

5.1 Methodology

The fixed-bed flow studies were carried out to evaluate their ability to remove *E. coli* during filtration process. The column was made from Perspex glass with inner diameter 8.5 cm. **Figure 3** shows a schematic diagram of the column setup used in this study. The pretreated media were filled in the column. To avoid channeling, the river water was pumped upward through the column at flow rate 50 mL/min. The flow rate was controlled by a peristaltic pump.

The water samples used in the column were taken from the Kerian River at coordinates 5° 07′38.61" N and 100° 35'44.24" E. The sand, GAC, and zeolite were oven dried for 24 hours at 105°C. Before placing the sand, GAC, and zeolite in the column, the column was washed with a solution of 3% acid nitric. The removal of *E. coli* in column test was observed in close exposure to light. This is due to the real condition in the aquifer which is close to sunlight exposure.

The *E. coli* was measured according to Method 9223B. The sample was transferred into the sterile vessel, and the water sample bottle is vigorously shaked 25 times within 7 seconds. The interval between shaking and measuring the test portion does not exceed 3 minutes. Aseptically the lid was removed, and the sample volume was adjusted to the calibrated 100 ml line of the sample container. Aseptically one packet of Colilert reagent was added to the 100 ml test bottle.

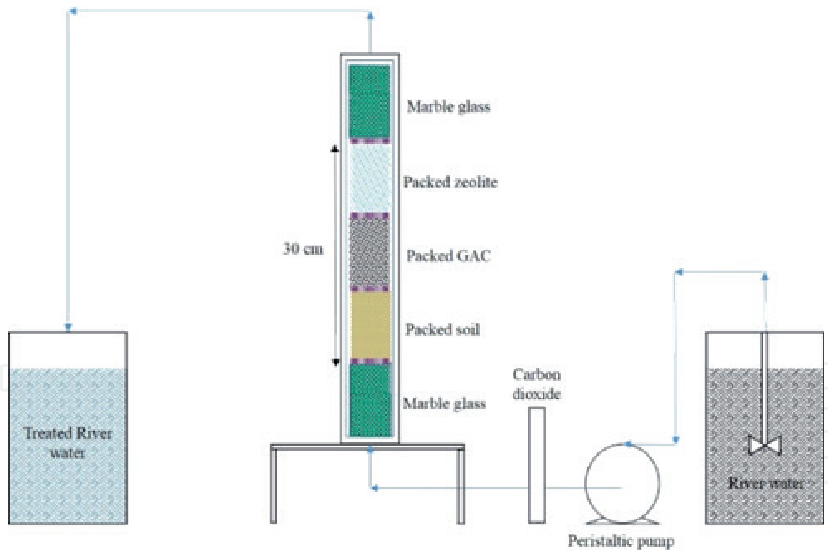

Figure 3.
Laboratory fixed bed column experimental setup.

Aseptic technique refers to a procedure that is performed under sterile conditions. The bottle was recapped and shaked until reagent was mostly dissolved. One hand was used to hold open the Quanti-Tray 2000. Well side was facing the palm of the hand. The upper part of the tray was squeezed so it bent toward the palm and gently pulled the foil tab to open the tray. Avoid touching inside of the tray or foil tab. The 100-ml sample was poured into the tray, and small wells are tapped two to three times to release air bubbles. The tray was placed with the sample into rubber insert so that the wells sat within the cutouts and rubber insert slided with tray into the sealer. The Quanti-Tray once sealed was incubated for 24 hours at 35 +/− 0.5°C. After 24 hours, the fluorescence light under UV light was counted which indicated as positive *E. coli*.

The measured *E. coli* using IDEXX was also validated with modified mTEC agar plates. Modified mTEC agar plates are prepaid powder by Arachem, BCBS2082V number. The powder was suspended in 1000 mL of distilled water for 45.6 g. The suspended powder was autoclaved and sterilized at 15 lbs. pressure (121°C) for 15 minutes. After that, the suspended powder was cooled to 45–50°C and poured into sterile petri plates. The filtered sample is placed at the top of agar and incubated at 35°C for 2 hours followed by incubation at 44.5°C for 22 hours. The modified mTEC agar contains selective and differential agents. Sodium lauryl sulfate and sodium desoxycholate are selective agents that inhibit Gram + cocci and endospore-forming bacteria. The modified mTEC agar contains the differential agent, 5-bromo-6-chloro-3-indolyl-β-D-glucuronide, which is catabolized to glucuronidase. Unlike the original mTEC method, the modified mTEC does not require the transfer of the membrane filter to another substrate. The positive colony was in magenta color. The analysis on surface morphology of the raw material was carried out using scanning electron microscope (Leo Supra 50 VP Field Emission, UK).

5.2 Result and discussion

In this study, 15 mixture components that are represented by soil, GAC, and zeolite bed height (in real site of RBF equal to distance of abstracted well water to river) were chosen for the optimization studies since they influenced the presence of *E. coli* in RBF abstracted water as well as volume of abstracted water. In addition, since the absence of *E. coli* and volume of abstracted water was concomitant, the experiments were done using high flow rate. This study determined the optimum ratio for combination of soil with GAC and zeolite that would support and improve the capability of *E. coli* removal compared to alluvial soil in RBF with a constant 50 mL/min flow rate. The removal of *E. coli* was less than 85% for soil with 81 and 82% removal as in **Figure 4**. In comparison with 70% soil combined with 15% GAC and 15% zeolite, the removal of *E. coli* was increased to 89%. Meanwhile, with 50% soil combined with 15% zeolite, the removal of *E. coli* was increased higher up to 90%. However, the combination of GAC and zeolite showed the lowest removal of *E. coli* compared to soil only by less than 50%. The honeycomb structure in GAC created the strongest biofilm layer which assisted the trap of microbe during high flow rate. Effective microbial adhesion and immobilization are essential for biofilm activities [39].

The GAC morphology (**Figure 5(a)**) showed that the surface structure and pore were well developed similar to honeycomb structure. The surface morphology of the GAC was also comparable to the analysis done by Hameed and Ahmad [40]. However, the adsorption of *E. coli* to GAC surfaces occurred on the outside of the

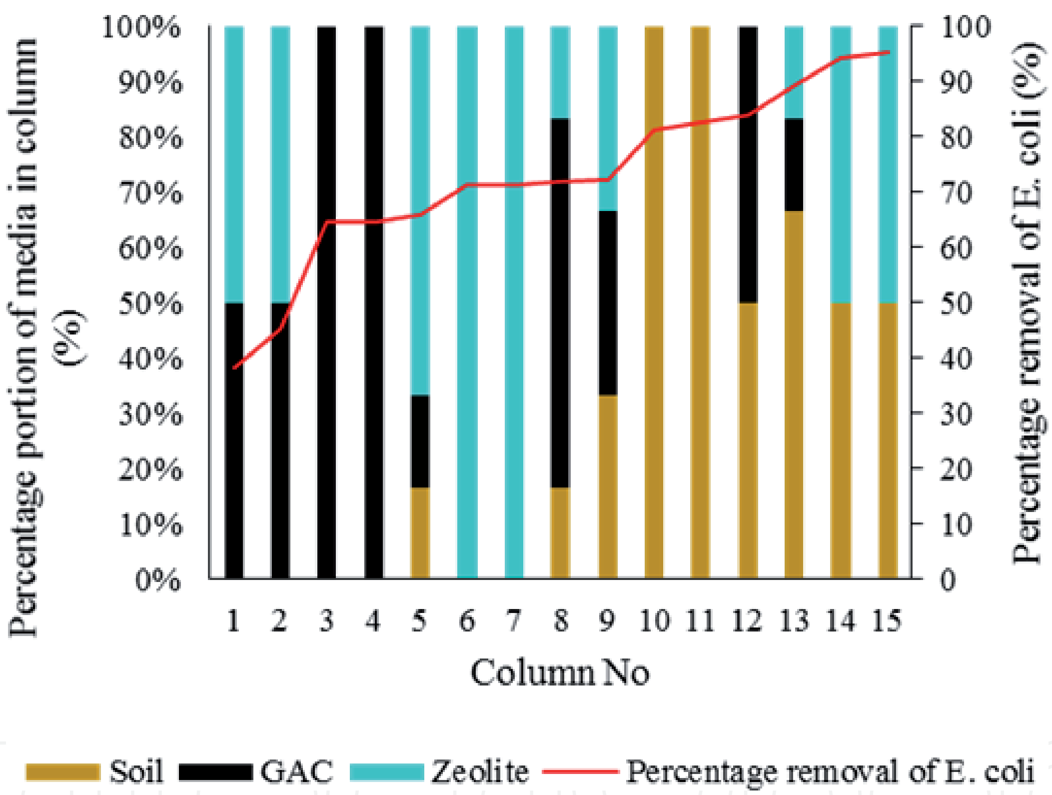

Figure 4.
Laboratory fixed bed column experimental setup.

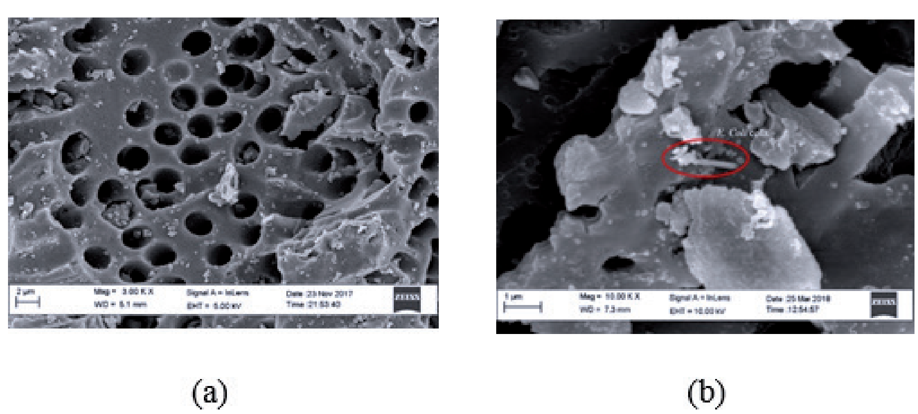

Figure 5.
The morphology of GAC for (a) before and (b) after adsorption with images of E. coli cells attach to surface.

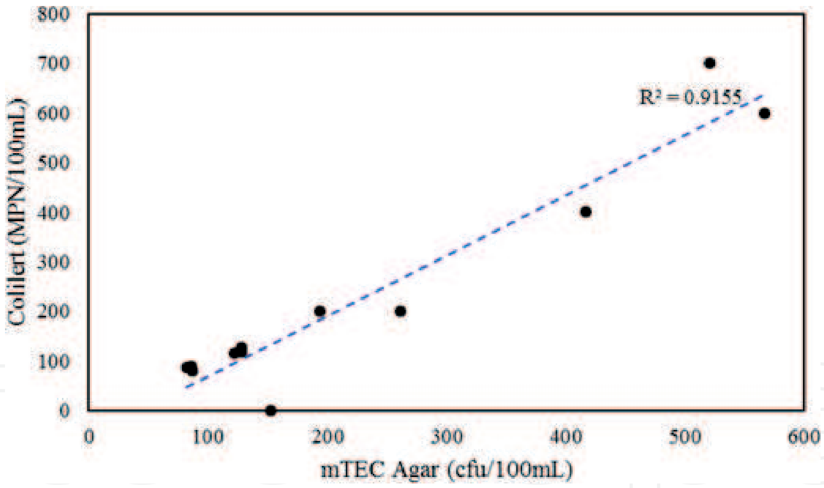

Figure 6.
Validation of measurement E. coli with using colilert and mTEC agar.

pore (honeycomb structure) as depicted in **Figure 5(b)**. *E. coli* adhesion to media surface is the initial step to schmutzdecke (biofilm) layer formation which later will create sticky surface and help in more adsorption of *E. coli*. The honeycomb structure provides strong physical confinement for the bacterial cells' adhesion and subsequently resists biofilm formation [41].

The enumeration of *E. coli* throughout optimization using Colilert. However, due to sensitivity and verification of the result, the mTEC agar enumeration method was used to increase the reliability of the result. **Figure 6** shows that the *E. coli* enumeration can be trusted due to linear R^2 of 0.92 which was acceptable (MPN acceptable values +20%). This means the results measured using mTEC agar are quite close to the mean value of MPN and in 95% of confidence limit for MPN measurement.

Until now, the health effects endemic to human for groundwater supply in Malaysia are not investigated. Casemore [42] notes that the occurrence of sporadic or pseudo-sporadic infection is particularly important in the context of groundwater-related infection. This is because the groundwater is often seen as pure quality and therefore not examined as potential sources of enteric infections that occur, thus leading to important effect.

6. Conclusion

The performance of RBF depended on alluvial soil particles' size distribution, soil gradation, and soil structure. From the monitoring, results show that the possibility of *E. coli* infection may happen. Thus, the purification method using artificial recharge seems important. In this study, the adsorption of *E. coli* by soil becomes higher in combination with GAC and zeolite. It was the honeycomb morphology of GAC that assists the attachment of *E. coli*. The schmutzdecke (biofilm) layer formation helps to enhance the *E. coli* adhesion to media surface which later will create sticky surface and help more adsorption of *E. coli*. The zeolite has higher CaO than other adsorbents; the attachment of *E. coli* in zeolite is based on mineral content. The aquifer is advisable but should not have too high or too low permeability for RBF because majority of removal mechanism was assisted by medium filter media permeability. The chemical usage technique in controlling *E. coli* in water treatment may not be a suitable method, whereby in a certain time, *E. coli* may resist to that chemical. Thus, from that reasoning, it's better to use the adsorption method.

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