

Protection of water: Robust of artificial barriers in application of riverbank filtration abstraction for water sustainability

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ARTICLE INFO

Keywords:

Riverbank filtration
Artificial barrier
Water protection
Water resource
Geoenvironmental

ABSTRACT

Malaysia is currently facing a water crisis due to prolonged droughts that are affecting the public's water supply. This is due to increasing climate uncertainty, making the protection of water resources a major issue worldwide. The term "water protection" refers to the evolving practice of maintaining the quality of source water through nature-based solutions, which are becoming increasingly important to ensure water safety and resilience for utilities and municipalities [5]. Since almost all the country's water treatment facilities extract raw water from river inlets, the situation is made worse by the increasing number of people in polluted waterways. As the government pledges quality of life for its population, the amount of water released from these rivers for public use—whether too little or too much, or too clean or too dirty—has become a priority. The Malaysian government has taken several actions to address the country's water problems, including releasing groundwater for certain regions as a supplementary water source. However, if water continues to be extracted from groundwater wells, it could put too much pressure on the aquifer and eventually cause the wells to release more water than they can hold and release the pollution such iron and manganese. To meet the demand for mass quantity and quality, this article proposes the use of riverbank filtration (RBF) pre-treatment techniques in water abstraction together with artificial barrier (AB). In the riverbank filtration and AB, it can balance the usage between river and groundwater. This can robust the water protection and environment management, to ensure the future generations, have access to clean water, and achieve water sustainability.

1. Introduction

Malaysia is experiencing a uniform temperature and copious rainfall climate. The annual rainfall is 2000–4000 mm which occurs between November–March and May–September. The volume of rainfall reaches to 670 billion m³ (East Malaysia) – 320 billion m³ (West Malaysia) [29]. There are more than 150 rivers in Malaysia, and it becomes the main source for water supply (97 %). However, most of the rivers have been

contaminated by the non-point source pollution causing the water treatment plant to enhance the treatment process such as the extra used of the chemicals in the treatment process. High chemicals concentration in water treatment can be detrimental to health. In fact, 93 % of people who use the water consisting of high chlorine content have the higher risk of getting cancer [64]. In addition, climate change becomes a great issue when Malaysia experiencing water shortage during dry season [11]. In order to ensure the portable water source is sustainable,

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<https://doi.org/10.1016/j.dwt.2025.101034>

Received 10 December 2024; Received in revised form 22 January 2025; Accepted 2 February 2025

Available online 5 February 2025

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Malaysia has planned various methods to overcome this problem. More than a century, direct abstraction from river was used in most of Malaysia's water treatment plant. The water treatment process used for riverbank water abstraction resource is much simpler than conventional water treatment process from surface water [7]. The surface water will be transferred into coagulation, sedimentation, filtration and sterilization (more than 3 step) treatment using intake facility as shown in Fig. 1 (Abstraction using intake facility). In 2013, Malaysia has started to use a new method for water abstraction which is riverbank filtration (RBF) which more nature solution as for water protection [5]. It is first used in Water Treatment Plant in Jeli, Kelantan, and Kuala Kangsar, Perak. The treatment for water supply is less (3 step only) when abstracting filtered water through the river bed and river bank as shown in Fig. 1 (Abstraction using riverbank filtration). As a sustainable natural treatment process which avoids or reduces the use of chemicals and produces biologically stable water, the system also improves water quality by removing particles (turbidity and suspended solid), organic pollutants, microorganism, heavy metals and nitrogen [47]. However, this is not reflecting the general conditions of the country's aquifers yet because Malaysia also have an area which an agriculture area such as Kedah which most land was used as paddy field sector. Due to that, the mechanism will be different. More than that the data on seasonal variations in water quality (dry and wet season) integrated into the design and evaluation of the RBF system which reflect the hydraulic conductivity of groundwater.

In India, RBF treatment efficacy has been extensively researched [27]. The RBF is situated close to the Yamuna River. The Yamuna River flows 1376 kilometres from its source at the Yamnotri Glacier in the Himalayas. The 490-kilometer stretch of the Yamuna River upstream and downstream of Mathura has been identified as a eutrophic segment based on hydro geomorphological, ecological, and pollution characteristics. This is primarily because of the discharge of sewage and industrial effluents into the river [2]. There are two water supply systems in Mathura. The first scheme, known as Site 1, uses pre-chlorination, while the second scheme, known as Site 2, uses a radial well (RBF system). About 4 kilometres upstream from Site 2 is Site 1. River water is pumped through an intake well at Site 1, where it undergoes pre-chlorination,

coagulation, flocculation, settling, and quicksand filtering. At Site 2, 13 radials totalling 522 m in length are positioned 15.5–18 m below the riverbed to collect subsurface water [32]. Aerated, filtered, chlorinated, and provided is the filtrate water. Water isn't coagulated or pre-chlorinated. Post-chlorination is the only method used. Fig. 2 shows the schematic flow diagrams for the collection and treatment operations at the two locations. Color 25 was lowered by around 50 % using bed filtering. Consequently, it was discovered that the average color of the radial well water was 22 CU.

The conventional treatment commonly involves screening, aeration, coagulation, flocculation, sedimentation, slow sand filtration, and chlorination. The chemical treatment and waste products will increase if the pollutants in surface water also increases. As shown in Table 1, the RBF process reduces the post treatment step from six to only two. And they are, the removal of heavy metals (usually iron and manganese) by either aeration, activated carbon filter or ultrafiltration, and chlorination for taste and odour. However, RBF may seem familiar with groundwater. In fact, both are not similar because RBF is near to the river meanwhile groundwater is far from the river. However, the operational of RBF has been discovered that both river and groundwater was abstracted in RBF, depends on the level of water in the river, [8,39].

The mechanism of pollutant removal in surface water is different from RBF. In surface water, mechanisms such as photodegradation may occur but not in RBF because it is blocked from sunlight [10,24,31,43]. During infiltration and travel through the soil and aquifer sediments, surface water is subjected to a combination of physical, chemical as well as biological process of filtration. The top few centimetres of the riverbank materials formed is a screen or filter media that removes the suspended solids present in the water which acts as a physical process [18]. Heavy metal, phosphorous and hydrophobic organic compounds present in the water are removed by adsorption into certain aquifer materials which acts as a chemical process. In the presence of biomass or when a particle becomes attached to the biofilm, the organic matter is further biodegraded by microorganism which acts as a biological process (firstly, under oxic conditions then later, under anoxic conditions). However, the water quality in most cases will improve by dilution of the source surface water with native groundwater [12].

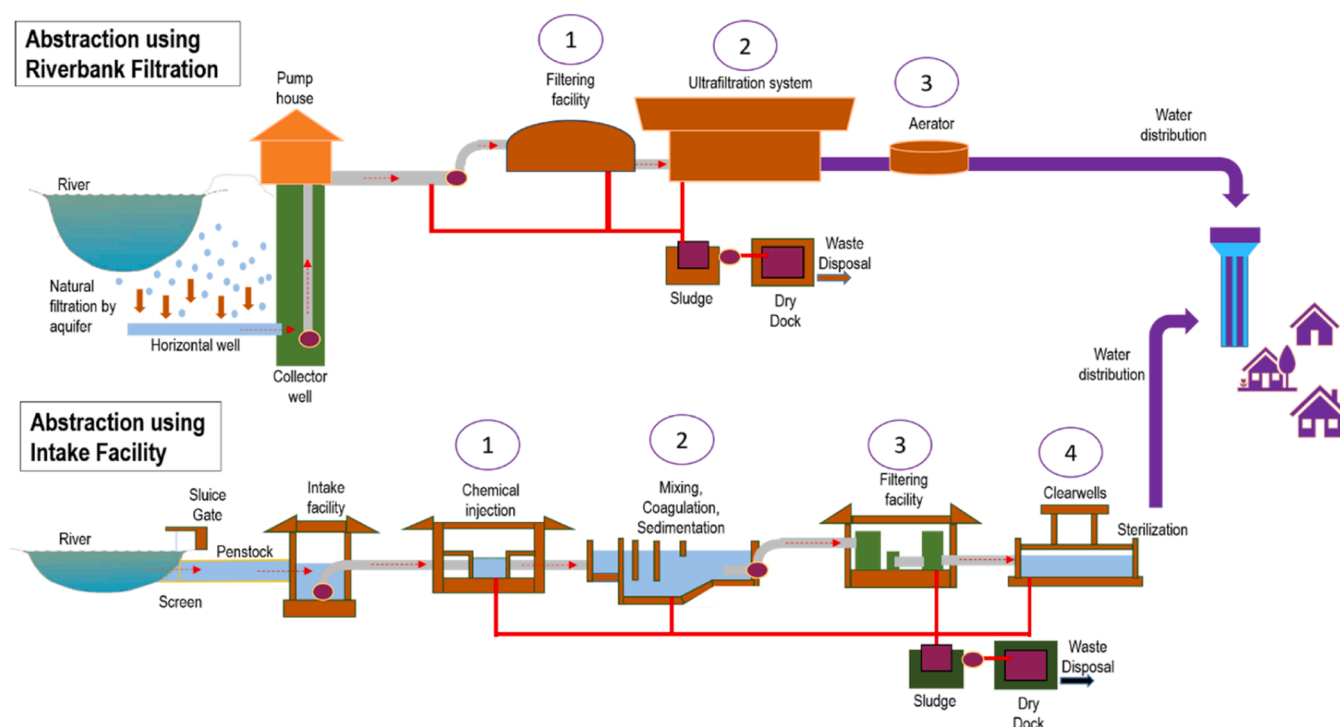


Fig. 1. Simplified of water treatment process for direct abstraction from river and filtered water through riverbed and riverside.

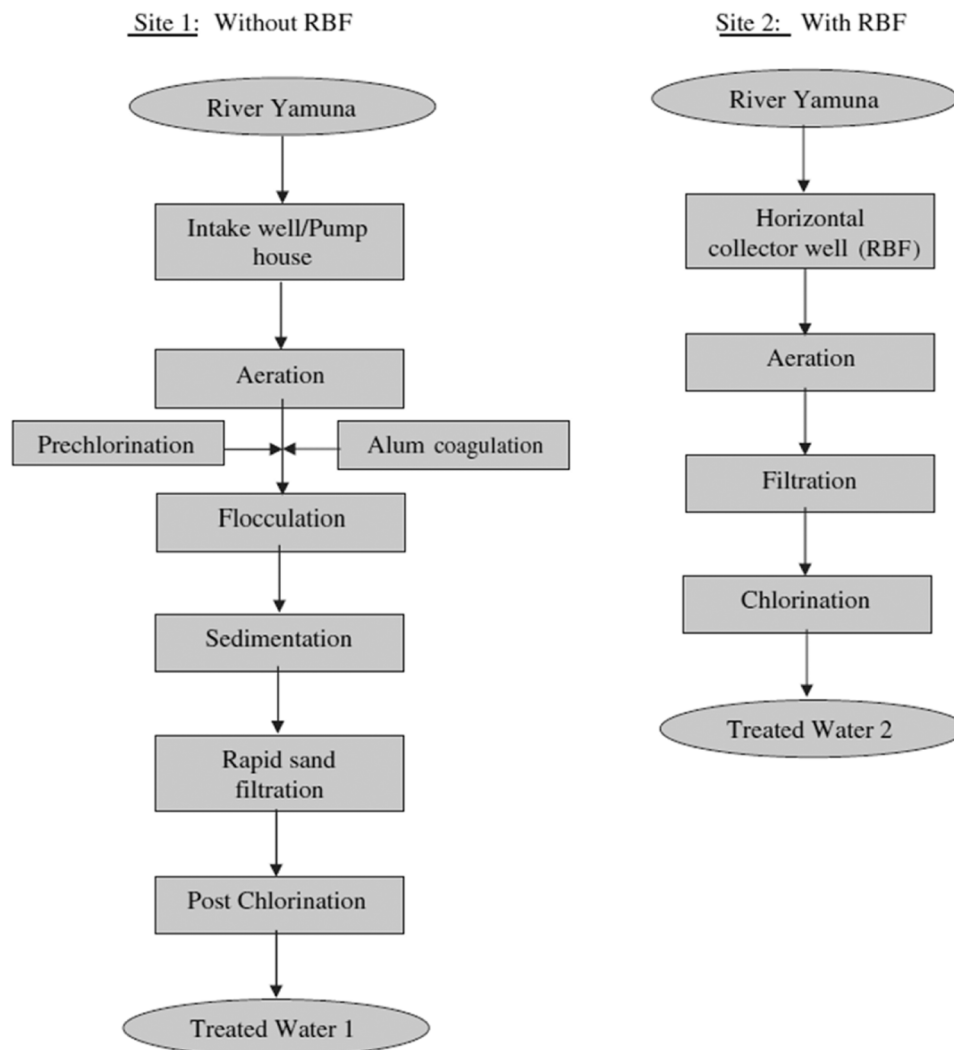


Fig. 2. Water supply scheme at Site 1 (without RBF) and Site 2 (With RBF) (Source: [2]).

Table 1
Comparison post treatments for surface water and abstraction from RBF.

Pollutants	Surface water Treatment	RBF water abstraction Treatment
Turbidity and colour	Slow sand filtration, aeration, coagulation, flocculation	-
Heavy metals	Aeration	Aeration, activated carbon filter
Dye	Slow sand filtration	-
Microbiology	Chlorination, slow sand filtration	Chlorination, ultrafiltration
Pesticide	Slow sand filtration	-
Odour	Chlorination	Chlorination

(Sources: [1])

In all that filtration process, there is a general agreement that the mechanisms where straining, adhesion, attachment, chemical adsorption, sedimentation and biological growth all operate to some extent according to the types of pollutants. Pollutant such as suspended solids is strained between soil pores. As for colour and COD, they are removed once a particle has been put in contact with the soil surface and this is known as a chemical adsorption mechanism. While phosphorus is removed by sedimentation mechanism. Meanwhile, to filter microbial, there are two potential mechanisms that can be used. Either by attachment cell to soil surface or by biological growth within the soil particles.

Interception happens when particles are carried by one of the streamlines closest to the sand grain and a brushing effect occurs. The summary of mechanisms during infiltration process is shown in Table 2.

The most important things to consider in an RBF design are the water quality and the capacity of water that can be abstracted. Therefore, to ensure water quality and capacity is enough, there are four basic important criteria that needs attention as it will affect the performance of the RBF. They are hydrogeological conditions, source water quality and mixing with native groundwater, distance of the well from the riverbank and spacing of wells as well as pumping rates, and sediment permeability. The effectiveness of an RBF in removing surface water contaminants depend largely on hydrogeological conditions. It is all about the soil microbiology, characteristic of the bank materials and streambed, as well as scouring characteristic [48]. In many countries, the alluvial soil aquifers are hydraulically connected to a water course. This would be the preferred sites for drinking water production [9].

In order to study more about RBF design, reviews of RBF designs from other countries are made and summarized in Table 3. There are two types of collector wells in an RBF. These are a horizontal well (HW) and a vertical well (VC). Some RBF sites applies both types of collector wells.

The depth and distance of the collector wells from the river is determined by the capacity of water that can be abstracted. A working RBF shows a decrease in RBF water levels when the distance of the well is further away from the riverbank. In addition to the decreasing RBF

Table 2
Summary of mechanisms during infiltration process. (modified from [38]).

Mechanism	Description	Pollutants	References
Straining	Particles larger than the pore space of the filtering medium are straining out mechanically Particles smaller than the pore space are trapped within the filter by chance contact	Suspended solid	Juan <i>et al.</i> (2017)
Adhesion	Particles become attached to the surface of the filtering medium as they pass by. Because of the force of the flowing water, some material is sheared away before it becomes firmly attached and is pushed deeper into the filter bed.	DOC and microbial	Vasiliki and Robin [62]
Attachment	The acquisition of cells from the bulk liquid by an existing biofilm	Microbial	Unger and Collins [61]
Chemical adsorption	Once a particle has been brought in contact with the surface of the filtering medium or with other particles, either one of these mechanisms, chemical or physical adsorption or both, may be responsible for holding it there	Colour and COD	Weiyan <i>et al.</i> 2018
Sedimentation	The particles settle on the filtering medium within the filter	Phosphorus	Regnery <i>et al.</i> (2015)
Biological growth	Biological growth within the filter will reduce the pore volume and may enhance the removal of particles with any of the above removal mechanisms by microbial degradation process.	Microbial & organic contaminants (pesticides, herbicides, odour compounds and pharmaceuticals)	Marcela [37]

water level due to increment of distance, it is found that there is no cross flow of natural groundwater in which the well could abstract the river water [53]. Which means, although the well is deeper and reaches groundwater, more river water is needed consistently in order to abstract a huge capacity of water. This is proven in a pumping test where the results show that the water in the well (below 60 m) comes from the river water [39].

However, if the well is short, the low-laying shallow aquifers are generally fragile, which can easily deplete due to anthropogenic activities and over exploitation of groundwater and agriculture. But the collector wells can be placed far from the river if the soil type is of sand and gravel, such as the RBF at Yellow River, China. In addition, the combination of HW and VW can maximise the water capacity such as the RBF at Elbe River, Germany. But in other cases, although they have a combination of HW and VW, clayey alluvial soil will limit the water capacity as seen at the RBF site at Lek River, Netherlands. At this RBF, it shows that the water capacity is only at 0.01 MLD in comparison to the RBF placed in clayey alluvial soil at Nakdong River, Korea which can

Table 3
Summary of RBF design from other country.

Country, river	Soil type	Collector well depth (m)	Distance from river (m)	Capacity (MLD)
China, Yellow River [25]	Sand gravel, coarse sand and sand	VW: 65 HW: -	272	0.02
Germany, Elbe River [15]	Fine sand and silt, medium sand and gravel	VW: 30–50 HW: 20	300	150
Netherlands, Lek River [19]	Fluvial sand or fluvial gravel with sandy clay at base	VW: 20–40 HW: -	370–906	0.01
Korea, Nakdong River [35]	Sand and gravel with several silt and clay	VW: 12.5 HW: -	150	10
Egypt, Nile River [1]	Sand and gravel, little clay	VW: 60 HW: -	20–80	22
India, Kali River [4]	Brownish red silty loam	VW: 18–23 HW: -	29–79	0.8
Kentucky, Ohio River [60]	Sand and gravel with several silt and clay. Limestone layer at 40–48 depth.	VW: 30 HW: 512	20	80
US, Great Miami River [56]	Most sand, some gravel and laterally bounded by limestone	VW: 60 HW: -	50	57–61
Malaysia, Sungai Semerak [6]	Gravelly sand	VW: 6–12 HW: -	10	25

abstract 10 MLD water capacity [21]. The reason being, for clayey alluvial soil types, a collector well needs to be built near the riverbank and at a deeper depth. For example, the collector well at Nakdong River, Korea which abstracts 10 MLD at 150 m distance from the river, but compare that to the collector well at Nile River, Egypt that has a capacity of 22 MLD.

The Kali River, India is a highly pollutant river which demands the RBF method to be used. However, the collector well can only abstract a mere 0.8 MLD of water due to the low transmissivity of brownish red silty loam alluvial soil. Hence, other than building wells nearer to rivers, limestones can be added to RBF sites with clayey alluvial soil to increase the transmissivity of the water, such as the RBF sites located at Ohio River, Kentucky and Great Miami River, US.

In Malaysia, the RBF site at Sungai Semerak contains gravelly sand and a shallow vertical well collector type. According to data obtained from the monitoring wells, the shallow geology of the RBF area is related to the alluvial deposition from the river which usually consists of upper fine, medium, and lower fine sand layers [35]. However, research also shows that there are some RBF sites that have silt or clay mixed with sand. And this exists at several depths in the layers [20]. The shallow collector well and its position nearer to the riverbank helps the RBF to avoid problems with iron and manganese. Hence, the largest capacity RBF site holds a water supply of 25 MLD. The actual biochemical interactions that sustain the quality of the pumped bank filtrate, however, depends on numerous factors, which includes aquifer mineralogy and the extent of the aquifer [23]. So, to manage and plan an efficient RBF design, the characterisation and understanding of the nature of the aquifer such as soil and rock types is crucial to elucidate their geochemical nature and its relation to abstracted water.

2. Protection of water in riverbank filtration: current technology

2.1. Water sources

The availability of water intake in riverbank filtration depends on the aquifer permeability. The water abstracted from RBF well mainly comes from the river [54]. However, sometimes the water may mix with the groundwater recharge in certain condition. The groundwater recharge for Malaysia has reached to 64 billion m³ together with groundwater storage by 5000 billion m³. It is more reliable than surface artificial storage which is only 25 billion m³ [40,55]. This is because the river water may reduce during drought seasons and depends more on the changes of climate. Although Pat *et al.* (2006) has stated that the groundwater can be affected by climate changes, but the possibility is only at depth of 2 m with a correlation coefficient 0.63. Recent research by Pratoomchai *et al.* [45] stated that future projection is needed in order to confirm the effect of climate change to groundwater resource. However, climate changes affect more on surface water than groundwater. Table 4 shows the result of the constant discharge pumping test for DW2. The first test was done on 7th December 2009, 1.24 MLD groundwater was abstracted from the well and the result of drawdown was 0.75 m during rainy season. The test on 22nd April 2010, successfully abstracted 2.17 MLD of groundwater and the result of drawdown was 2.02 m during drought season. The third test was done on 10th October 2010, resulted in 3.07 MLD abstracted groundwater with 2.63 m of drawdown result during drought season. The pumping tests also indicated that the seasonal changes did not affect the volume of water abstracted from RBF. However, clogging problem during RBF operational cannot be avoided. The solution for the problem is to create a shock load from well to river or excavate the riverbed surface (Pieter *et al.*, 2006). Nevertheless, the problems will reoccur. The problem with shock load procedure occurs when some dangerous pollutants which already attached in local soil aquifer will dilute again into river water and risk to river aquatic life [22]. When the riverbed is excavated, it will destroy the structure of the river.

2.2. Water pollution

The quality of water from riverbank abstraction is cleaner and reliable than surface water abstraction. The polluted river such as at Khabarovsk, Russia changed to use river bank filtration method as an alternative source of water supply [33]. The compatibility of RBF system application depends mainly on the aquifer condition at a particular place. Table 5 is the summary of heavy metal recorded in Langat River, DW2 and PW1. The samples were collected on 9 October 2010 and analysed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) method previously by NAHRIM. The calcium (Ca), carbon (C), chlorine (Cl), iron (Fe), magnesium (Mg) and sulphur (S) are major solute concentrations found in this groundwater [17]. Sulphur and carbon are the highest inorganic trace element found in all sampling points (river and well). Above the 250 mg/L level, sulphate can impart a taste to the water and may cause a laxative effect. However, from an aesthetic point of view, the H₂S molecule is probably the most offensive by having the distinct and unpleasant odour of rotten eggs. When this water is pumped to the surface, the rotten egg odour is detected. Low concentrations of some metals such as Copper (Cu), Manganese (Mn) and iron are

Table 4

The result of constant discharges pumping test for DW2 (Source: Rashidet al#, 2022).

Date	Pumping hours	Q (m ³ /h)	MLD	Drawdown (m)
7 December 2009	72	51.6	1.238	0.75
22 April 2010	168	90.2	2.165	2.02
10 October 2010	72	128	3.072	2.63

Table 5

Result for heavy metal using ICP for Langat River, PW1 and DW1, Dengkil, Selangor (Source: NAHRIM 2011). [40]

Heavy metals	Langat River	PW1	DW2	Standards
Aluminium	0.032/	0.004	0.004	0.2
Arsenic	0.002/	0.001	0.001	0.01
Barium	0.032	0.087 /	0.034	0.7
Boron	0.052/	0.048	0.025	0.5
Bromine	0.025	0.059/	0.021	0.025
Calcium	3.400	4.673 /	0.919	-
Carbon	19.381/	18.886	10.906	-
Chlorine	5.005	5.152 /	2.357	250
Chromium	0.001	0.001	0.001	0.05
Cobalt	0.000	0.000	0.001/	-
Copper	0.019 /	0.014	0.010	1.0
Iodine	0.001	0.001	0.000	-
Iron	0.118	0.127	0.633/	0.3
Lithium	0.002	0.002	0.003/	-
Magnesium	2.440	6.621 /	2.519	150
Manganese	0.004	0.234/	0.122	0.1
Mercury	0.001	0.001	0.002/	0.001
Sulfur	40.000	43.000/	42.000	-

necessary for all living organisms, whereas most of the metals present a toxicity hazard at high concentrations. However, the analysis from ICP-MS recorded that groundwater samples have slightly exceeded the permissible limits. By referring to Table 5, concentration of Fe and Mn in DW2 have exceeded the limit standards, where Fe concentration was 0.632mg/L and Mn concentration was 0.122 mg/L. High Fe and Mn concentrations can result in aesthetic problems due to the reddish staining of bottom streams. Consequently, high dissolved Mn or Fe concentrations are usual in such systems and can be problematic for the production of drinking water [14,23]. Thus, this problem can be solved by using a preferential flow induced through the construction of two sand filters crossing the upper clay layer [16]. Sampling results from the DW2 test wells showed that the microorganism count were significantly reduced during the passage in bank infiltration (river bank filtration) and capable to achieve more than 99.9 % removal of *E. coli* and total coliform as shown in Table 6, though high colony counts were observed in RBF well during floods events [26,51]. Sampling was done on 24th of April 2010 by NAHRIM and *Giardia* cysts were occasionally detected in the river waters which varying from 2.9 cysts/L to 1 cyst/L, while for well water the samples obtained from the site were negative for both *Cryptosporidium* oocysts and *Giardia* cysts. Weiss *et al.* (2005) found that bank filtration have the potential as a significant barrier for the transport of *Cryptosporidium* and *Giardia* from side river to production wells. Gollnitz *et al.* [13] and Weiss *et al.* [63] monitored *Giardia* cysts and *Cryptosporidium* oocysts in the Great Miami River and gained a 99 % removal for more than 100 years. It had been proved that the protozoan pathogens *Giardia lamblia* and *Cryptosporidium parvum*, which are known to be extremely resistant to conventional means of disinfection [34,58] can be treated by RBF method. From the result of different sites (Tables 7 and 8), the well water quality was better than river water. However,

Table 6

Result for bacteria analysis (Langat River and DW1) and parasitological analysis (SW1, SW2 and DW2) at Dengkil, Selangor (Source: NAHRIM 2011). [40]

Bacteria analysis		
Samples	Total coliform	<i>E. coli</i>
Langat River	> 2420 MPN/100mL, 35.5 ± 0.5°C/24h	1414MPN/100mL, 35.5 ± 0.5°C / 24 h
DW2	< 1.0 MPN/ 100 mL, 35.5 ± 0.5°C / 24 h	< 1.0 MPN/100mL, 35.5 ± 0.5°C / 24 h
Parasitological analysis		
Samples	<i>Giardia</i> cysts/L	<i>Cryptosporidium</i> oocyst/L
SW1	2.9	0
SW2	0.1	0
DW2	0	0

Table 7

Water quality characteristic at Kuala Kangsar, Perak (Source: Rashid et al#, 2022).

Test parameters	Unit	Results								Standard
		Perak River	MW1	MW2	MW3	MW4	MW5	MW6	PW	
pH	-	6.33	6.02	5.69	5.25	5.19	5.7	5.64	5.89	6.5–9.0
Color (True color)	PtCo	91	71	40	20	7	98	109	47	15
Turbidity	NTU	21.4	13.1	1.01	0.61	0.49	28	1.3	1.12	5
Dissolve oxygen (DO)	mg/L	6.59	0.04	0.74	0.19	0.67	0.18	0.3	2.26	-
Total Dissolve Solid (TDS)	mg/L	35.1	188.5	151.4	102.7	96.9	146.3	97.5	128.7	1000
Iron	mg/L as Fe	0.59	25.5	14.1	9.6	9.5	13.3	9.1	7.9	0.3
Manganese	mg/L as Mn	3.9	2.5	4.3	1.2	3.4	3.6	2.2	1	0.1

Table 8

Water quality characteristic at Dengkil, Selangor (Source: Rashid et al#, 2022).

Test parameters	Unit	Results								Standard
		Langat River	MW1	MW2	MW3	MW4	MW5	MW6	PW	
pH	-	6.88	5.34	5.66	5.783	5.30	5.38	5.57	5.31	6.5 – 9.0
Color (True color)	PtCo	22.50	5.33	20.33	27.333	8.00	7.00	17.67	8.33	15
Turbidity	NTU	324.75	3.71	0.67	147.1	0.55	1.11	90.28	0.41	5
Dissolve oxygen (DO)	mg/L	5.56	2.96	2.38	2.99	2.35	2.39	2.43	1.94	-
Total Dissolve Solid (TDS)	mg/L	117.60	46.76	52.66	109.00	50.60	60.55	126.30	70.10	1000
Arsenic	mg/L as As	0.07	NA	0.064	NA	NA	0.126	0.108	0.086	0.01
Chloride	mg/L as Cl	3.36	NA	NA	NA	NA	NA	NA	NA	0.200
Iron	mg/L as Fe	4.92	1.30	1.61	1.56	1.39	1.24	2.36	0.61	0.3
Magnesium	mg/L as Mg	1.92	3.05	3.47	4.57	1.98	3.14	4.10	2.05	150
Manganese	mg/L as Mn	0.09	0.95	1.47	1.14	0.67	0.95	0.9242	0.35	0.1
Zinc	mg/L as Zn	0.07	0.57	0.57	0.55	0.52	0.55	0.72	0.32	3

some values for heavy metals and microorganism were exceeding the standard limit. The quality of water abstraction from riverbank filtration usually produces a good water quality as well. According to the experience from other countries which apply RBF technique, in certain situation, the quality of the water abstraction may reduce. In conclusion, several pollutants are not permanently removed for long period in RBF operation.

The post treatment after RBF depends on the water abstraction water quality. Each RBF site has different techniques and steps for post-treatment. Previous studies showed that the most common pollutants which occur in RBF sites are iron and manganese (Enrico *et al.*, 2016; Pieter *et al.*, 2006; Adlan *et al.*, 2016). The treatments used to remove these contaminants in water are aeration, activated carbon filter, and ultrafiltration methods. The second main contaminant occurrence is the taste and odour which is usually removed by chlorination. Then, the third contaminant is microbiological which is solved by using ozonation and UV disinfection. All these post-treatment techniques are commonly used at RBF sites and is summarised in Table 9 below. Meanwhile, there are RBF sites which do not use post-treatments as a mean for direct usage such in China. However, they may face oocyst problem in several years to come.

The post-treatment step in most RBF sites usually focuses on iron and manganese treatments which will result in the usage of aeration, activated carbon filter and ultrafiltration treatment processes. The occurrence of *E. coli* in the intake water is usually solved by using a disinfection treatment which normally contains the chlorination method. The limitation of this treatment has been discussing in the above section cannot be ignored. The occurrence of pollutants can be worse during shock load and clogging. And because of that, an artificial barrier seems important which can help increase the hydraulic conductivity of the underground water flow and reduce the pressure load to the aquifer during clogging and enhance the pollutants adsorption during shock load. This can reduce the usage of chemical treatments and strengthen the RBF barriers.

RBF is promising to increase the water protection plan since it is very beneficial. However, since it is a natural treatment, the water protection should be strengthened due to some reasons. The quality of water

Table 9

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

Country	Treatment schemes	Comments
Netherland	Aeration, rapid sand filtration, activated carbon filtration and UV disinfection (Sources: [30])	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 (Sources: [57]).	Sudden increase of pollutants (cause of flood or natural disaster) may break down the ultrafiltration system and high maintenance of ultrafiltration system.
Germany	Ozonation, biological activated carbon filters, UV and safety chlorination (Small amount). (Sources: [41])	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. (Sources: [57])	The usage of filtration as to filtrate the precipitation of iron and manganese in aeration section build an metal clogged filter. This may contribute to demenarilaziton during oxic condition.
Egypt	Aeration, filtration and chlorination (Sources: [53])	-
Finland	Two stage sand filtration, Disinfection with UV and chlorination (small amount). (Sources: [28])	-

abstracted from the RBF system depends on the alluvium and ground-water characteristics of the site [42]. The RBF may appear inability to remove certain biological, inorganic, and organic contaminants only when associated with limitation by hydrology and dynamics of the river and groundwater [50]. This article suggests applying an artificial barrier in riverbank filtration. The application of barrier is necessary because the possibility of accidental contamination enables on water resources is inevitable. For example, the spectacular spills in Sandoz accident on November 1, 1986, [59] underlined the need of barrier for sanitation

measures and pollution control. According to Rashid et al. [46], the immediate results are the permeability increased with the percentage of artificial barrier with consistent removals of pollutants due to the existence of Schmutzdecke layer. It is suggested that the artificial barrier (AB) to consist of laterite soil, granular activated carbon (GAC) and zeolite which suitable for the growth of Schmutzdecke layer.

3. Future expectation: application of artificial barrier

Water quality from RBF is proved to be better than river water quality. This can be validated by referring to the water quality from two riverbank sites at Dengkil, Selangor and Kuala Kangsar, Perak. Nevertheless, results from the analysis of water samples have shown the presence of some pollutants and in some conditions contaminant were not removed during RBF process. Due to that, it is necessary to take an effort

to place an artificial barrier near riverbank filtration rather than treating the water after it has been abstracted from well. The artificial barrier in riverbank filtration site is necessary in order to preserve the safety of the water. The design of artificial barriers are suggested beside the borehole as shown in Fig. 2 below. The artificial barrier is a man-made vertical barrier to pre-treat the abstraction water from the water intake structure. It is a mixture of laterite soil, granular activated carbon (GAC) and zeolite. There are two types of borehole at riverbank filtration, (i) vertical and (ii) horizontal. Riverbank filtration is usually applied with borehole nearest to river bank as shown in Fig. 3(a). After the abstraction of water in borehole, the water will either be pre-treat or directly delivered to consumer usage. The enhancement of river bank filtration water treatment suggested is designed in Fig. 3(b). The characteristic for location of borehole must not be too far from river and not too near to the river. This is to maintain stable the usage of groundwater and river

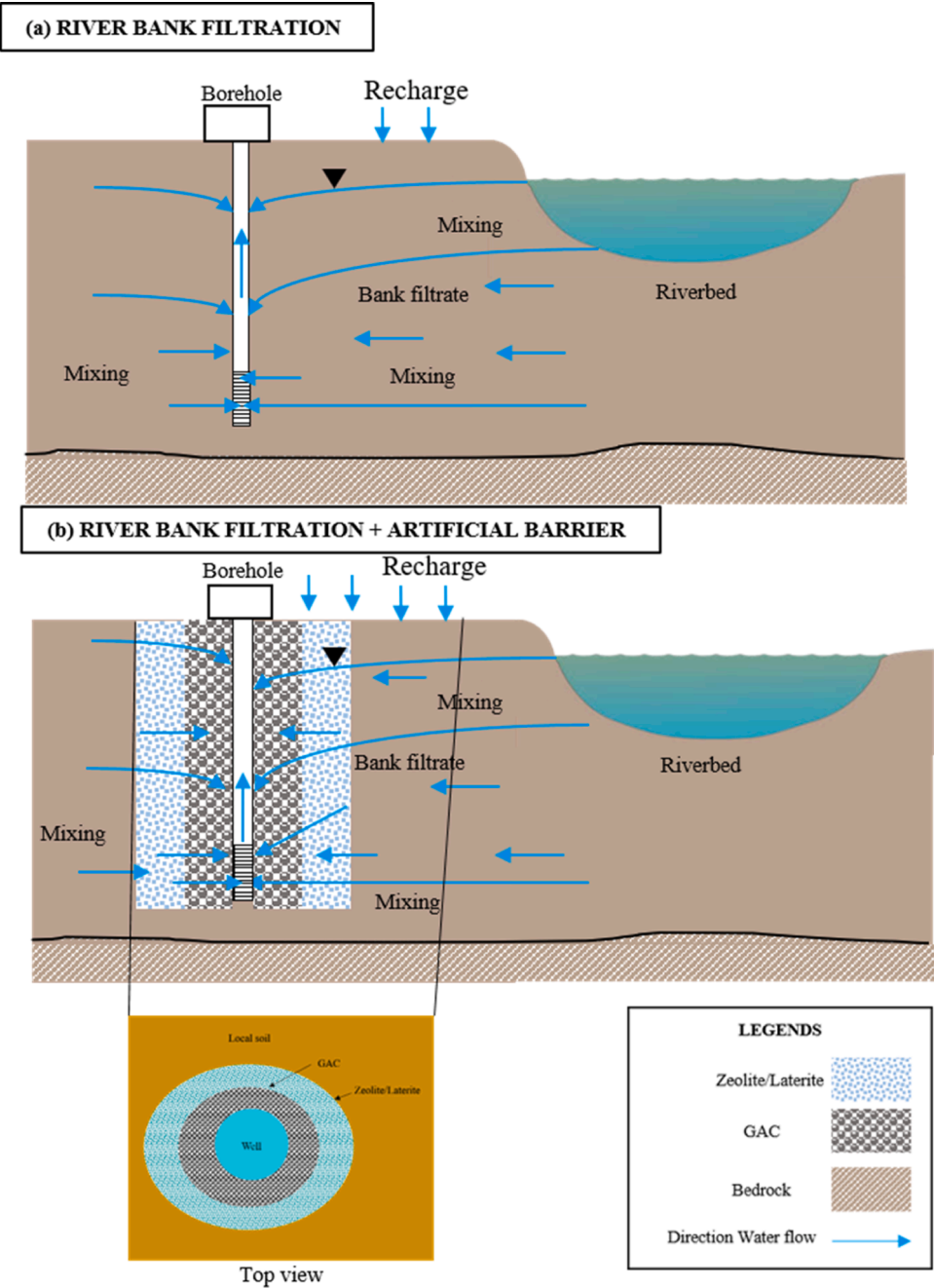


Fig. 3. Processes involved in RBF and RBF with artificial barrier.

water. The capability of laterite soil, GAC and zeolite to remove pollutants is well known. However, the application of these in riverbank filtration has yet to be published.

All three media were having high permeability based on the permeability test results. The highest permeability was GAC media materials, as stated in Table 10. Table 10 shows the viscosity value for each adsorbent. From the result, the permeability values of laterite soil, activated carbon, zeolite and the mixture of the adsorbent were 1.77×10^{-7} m/s, 1.21×10^{-3} m/s, 6.87×10^{-3} m/s, 1.13×10^{-3} m/s, respectively. Laterite soil has the lowest value because the particle size of the soil is small which is less than $150 \mu\text{m}$ (Al-[3]). While the activated carbon value indicated that the permeability was rapid because both adsorbents were in granular size. To implement this to the artificial barrier, the three adsorbents were mixed in ratio of 1.25: 5: 1.5 (zeolite: activated carbon: laterite soil) and tested. The significant increase in permeability for mixed media indicates that there are a good bonding or interaction between the laterite soil particles, activated carbon and zeolite. Hence the development of large pores and cracks was minimal. Therefore, the artificial barrier is strongly proposed for application at the riverbank with high clay content. Based on the permeability test results, the mixture of the adsorbent is suitable to be used as barrier for RBF [52].

4. Benefits application of artificial barrier in RBF

The application of artificial barrier in RBF can robust the water protection. The quality of water abstracted will be safer than the usage of natural soil because it can increase the pollution removals and protect from spill accident. This artificial barrier not only can be applied in RBF but also can be applied at houses that use groundwater for daily use. Application of artificial barriers is to improve the level of pollutants removal of the riverbank filtration. While pollutants still can be treated after abstracted out of the ground, the use of chemicals can be detrimental to health. For instance, the use of chlorine has proved to be harmful to health [64]. By using artificial barrier, the water protection plan for water infrastructure can be improved toward resilience of climate change. The overall cost for application of artificial barrier can be assumed is higher than without artificial barrier due to cost of materials of artificial barrier. However, the investment is worthy since it includes the prevention, remediation and protection of water cost [44]. In the future, the operational and maintenance cost are reduced due to less treatment operation used. With no disinfection treatment, it will reduce or eliminate the by-products. Such been applied by other similar application of artificial barrier it is permeable reactive barrier and geological barrier at United State and Germany [36,49].

5. Summary and future direction

Riverbank filtration is a multibarrier and sustainable application that uses natural treatment. For the time being, the RBF system promotes a lot of benefits. In long term period, the treatment efficiency may deteriorate, by using the local soil as a major natural media for pre-treatment of water, there are some disadvantages for short and long term condition as discussed. Therefore, it is highly recommended to use the artificial barrier which can robust the water protection of RBF which maintain balance and stable the usage of river water and groundwater. The application of artificial barrier as pre-treatment in RBF system will be more efficient since it can help to remove pollutants better and improve the capacity of abstracted water. It also increased the permeability of water to move from river of groundwater into well. The proposed media namely laterite soil, zeolite and GAC are appropriate to be a combination in artificial barrier. This research strongly suggests the use of artificial barrier in the RBF. However, further research on the effect of clogging and long-term effects on RBF site is needed.

Table 10

Permeability value for each adsorbent (Source: Rashidet al#, 2022).

Adsorbent	Permeability Coefficient, K	Permeability
Laterite soil	1.77×10^{-7} m/s	Moderate
Granular activated carbon	1.21×10^{-3} m/s	Rapid
Zeolite	6.87×10^{-3} m/s	Rapid
Laterite soil + Activated carbon+zeolite (with ratio 1.25: 5:1.5 indicated the optimum dosage obtained from batch study)	1.13×10^{-3} m/s	Rapid

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

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

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