

RIVERBANK FILTRATION (RBF) INDEX AND EFFECTIVENESS OF RBF AT WEST MALAYSIA

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ABSTRACT

Drinking water supply in Malaysia is based on surface water abstraction (98%) and groundwater (2%). As Malaysia is currently facing problems with climate change and the pollution of surface water by industrial, agricultural and municipal inflows, riverbank filtration (RBF) would offer in situ water treatment process and a low cost alternative for pre-treatment of raw water for potable use. The objective of this paper is to evaluate the potential of selected riverbank filtration in Langat River, Linggi River and Muda River, Malaysia based on drilling at potential sites and monitoring of both water level and water quality parameters. Analysis of the feasibility of RBF for three sites based on hydrogeology have been also evaluated. The evaluation of three sites receiving a bank filtration share of more than 80 % and producing drinking water has proven the feasibility of riverbank filtration in Malaysia. Main issues for the feasibility of RBF in Malaysia are found to be the hydraulic connection between surface waters and the adjacent aquifer and the surface water and groundwater quality. The Malaysia Rivers has hydraulic connection with a Quaternary aquifer that is comprised of coarse sandy riverine sediments. The coarse sandy riverbed and coarse aquifer materials have a sufficient hydraulic conductivity for RBF. As an interesting aspect, the siting of the pumping well near to the river is also considered. It is recommended that, wells are constructed at short distances from the river bank, to get a high share of bank filtrate and reduced the iron (Fe) and manganese (Mn) from the borehole.

Keywords: RBF index; bank filtration share; riverbank filtration; water quality of bank filtration; enhancement of river.

1 INTRODUCTION

El Nino phenomenon will affect water resources in Malaysia. Malaysia is blessed with stable water quantity and quality and easy access of conjunctive use surfacewater and groundwater management. Thus, riverbank filtration (RBF) is suitable to be adopted in this country and is an important of groundwater exploitation. The design and concept of RBF was common in Europe since 1870 (Schubert, 2002). In Switzerland, France, Finland, Hungary, Slovakia, Germany and Holland, the proportion of total drinking water supplied by RBF has reached 80%, 50%, 48%, 45%, 50%, 16% and 5% respectively (Tufenkji et al., 2002; Hiscock and Grischek, 2002). The conjunctive use of surfacewater and groundwater resources can be used through RBF, which stimulate and increase the recharge of river water to the aquifer (Shamsuddin et al., 2014). RBF is the infiltration of river water into a well through the riverbed and underlying aquifer material such as sand. This is a natural filtration process in which physic-chemical and biological processes play a role in improving the quality of percolating water. After a certain zone of mixing and reducing, the infiltrated water is at its cleanest, almost all river contaminants are removed. Wells are installed in this zone to pump the water to be used for drinking. The purity of this water and its suitability for drinking is outstanding, even in examples where there is an event that introduces a shock load of contaminants in to the river. Due to the geologic media's ability to remove the contaminants and travel time of water abstracted for natural filtration, the impact of such an event is minimal. In Malaysia, the National Hydraulic Research Institute of Malaysia (NAHRIM) evaluated the feasibility of developing the RBF system along the major rivers to mitigate water shortage problem of water supply for domestic and industrial consumption. One of the main tasks in the RBF development project is the feasibility of site to develop the RBF system. The success of RBF depends on favorable hydrogeological conditions near the river. Riverbank filtration relies on the ability of a well to induce recharge from a nearby surfacewater source, with the degree of hydraulic connection between surfacewater and groundwater is often the factor that limits wellfield capacity. However, it is site specific and requires extensive site investigations and pilot studies to assess its feasibility based on local conditions. In Malaysia guidelines or index system of RBF was not available to evaluate the suitability of RBF and the transfer of this sustainable and multiple-contaminant removal technology. Though very appropriate for both developed and developing countries, RBF has not been utilized (fully) in developing countries due to lack of knowledge and tools/methods for design of such systems. Factors affecting performance of RBF System such as site specific,

conditions source (river, lake), geology and soils, geohydrology (alluvial, unconfined aquifer, aquifer depth (depth to water table), permeability (hydraulic conductivity), travel distance, well placement and spacing between wells, travel (residence), time well placement and operation (pumping Rate) and permeability (conductivity) is more important factor to develop the index system. Design components for RBF system including number of wells (production capacity per well), spacing between the wells, distance of the wells from the riverbank, share (%) of river water and native groundwater. Water quality obtained from the RBF system, and post-treatment requirements will be considered in the index system of RBF. In this research, the downstream river basin of the Langat River, Linggi River and Muda River was set as the study area and the potential RBF index suitable area for RBF was evaluated. Based on the analysis of natural geography and hydrogeological conditions, an index system was established to evaluate the suitability of RBF along the main of the river in the study area. The aim of this research is to find potential suitable areas for future water development plans and conduct further detailed investigation of RBF systems. The specific goal of RBF is mainly to provide sufficient water resources with good water quality. A multi-criteria RBF evaluation index system was established based on water quantity, water quality, the development and utilization conditions of groundwater resources and the interaction intensity between surface water and groundwater. The index weight and detailed score criteria were all based on specialist marking methods, which is more effective for a specific site but may not be applicable to other areas.

2 STUDY SITE

RBF in West Malaysia aims to achieve the strategic goals of improving drinking water production including an improved availability and increase sustainability of drinking water supply at high quality, at low cost and with a limited generation of waste or contaminant product. This RBF pilot study site offers important advantages as the researchers can evaluate the RBF index of RBF technique for River in Malaysia. For this downstream river basin of the Langat River, Linggi River and Muda River, and was calculated the feasibility RBF index based on the parameters affecting yield in RBF systems. Three study sites for this study were chosen based on the following criteria:

2.1 Bank Infiltration systems

2.1.1 Langat River

The Langat riverbank corridor area at the Jenderam Hilir located approximately some 5 km south of Putrajaya was chosen and has been identified as potential site to do the feasibility study of using RBF system. It extends between latitude $2^{\circ} 53' 28.56''$ N - $2^{\circ} 53' 39.75''$ N and longitude $101^{\circ} 42' 03.78''$ E – $101^{\circ} 44' 14.58''$ E, covering an area of 10 km² radius (Figure 1.1). The aquifer system in the study area consists of alluvial deposits of sand, silt and gravel which form shallow aquifer. The unsaturated zone sits on the aquifer consists of clay. The thickness of this clay layer is about 1-3 m. The aquifer is mostly of fine to coarse grained sand with mixture of gravel. The thickness of aquifer layer ranging from 5-20 m. It can be locally heterogeneous due to the presence of beds of fine to coarse-grained sand. Based on drilling information, gravelly sand or sandy gravel aquifer layer are overlain by layer of clay, while some areas are overlain by a layer of low permeability fine sand or silt which make the aquifer unconfined and semiconfined depending on locations. Bedrock in the study area is located at depths of 20 m. Due to the presence of sandy gravel which has high porosity and transmissivity, and connection to the river, during high river flow, water from the river recharged the aquifer. Meanwhile during the river low flow, groundwater is discharged into the river. Rechargeable between river and groundwater through riverbed layer can be slow or fast depending to the thickness of hyporheic zone layer.

The average mean monthly flow at the study area is about 32.15 m³/s. The 80% dependable flow for Langat River is 19 m³/s. The average low flow is 4.76 m³/s for year 1978 – 2013. The riverbed permeability is 0.4 m /day. The result of the river survey has shown the cross sections single thread channel with bank full width ranging from 22.75 m to 50.20 m that represents a medium size river. Two new test wells i.e. TW1 and TW2 with outer diameter of 250 mm, at a depth of 14.50 and 15.42 m respectively were constructed to determine the hydraulic parameters of the wells and aquifer. The pumping test at TW2 was started at a rate of 12.90 m³/hour with static water level of 3.24 m below top of casing (TOC). The flow rate was constant throughout the test at 64.50 m³/hour. The total drawdown at the end of the one day pumping test was 3.16 m. Recovery test in TW2 after step-drawdown test shows that the water level recovered back to 3.53 m after 7 hour pump stop with efficiency of 90.82%. The static water level was 3.50 m and the final water level was 7.03 m below ground level. The T and K values for TW2 were 42.16 m²/hour and 2.72 m/hour. According to this aquifer test, the range of travel time from river water to recharge the aquifer is averaged at 3-4 days. The travel time was estimated by dividing K in m/day with the aquifer thickness. The test well TW2 has successfully shown that well-constructed along the river banks is capable of yielding significant volume of water with very much better quality. Recovery in TW2 shows that the water recovered from final water level (7.03 m bgl) to 4.2 m bgl within 1 hour (80%), then slowly recovered after that. For TW1, a step-drawdown test (three steps), a 72 hours constant discharge test. The pumping test at TW1 was started at a rate of 6.53 m³/hour with static water level of 6.47 m below top of casing (TOC). The flow rate was constant throughout the

test at 10.10 m³/hour. The final water level was 7.44 m. The total drawdown at the end of the one day pumping test was 0.97 m. The recovery test in TW1 after step-drawdown test shows that the water level recovered back to 6.66 m after 1hour pump stop with efficiency of 80.41%. The constant discharge test was carried out with a pumping rate of 10.10 m³/hr. The static water level was 6.09 m and the final water level was 7.45 m below ground level. The T and K values for TW1 were 9.24 m²/hr and 0.63 m/hour. The drawdown of TW1 was very low, this shows that the well is capable of producing much higher amount of water but due to limitation of effective aquifer layer and pressure from thickness clay layer on top of aquifer, can cause slow recharge from the river. According to this aquifer test, the range of travel time from river water to recharge the aquifer is averaged at 1-4 days. The travel time was estimated by dividing K in m/day with the aquifer thickness.

2.1.2 Linggi River

The location of the RBF study is located at Water Treatment Plant Linggi River, Negeri Sembilan. It is located at the riverbanks of the Linggi River. Linggi River Water Treatment Plant supplies 60% and 100% of the water requirements for Seremban and Port Dickson, respectively (Figure 1). A total of 35 exploration wells of 50 mm diameter were constructed as a preliminary assessment on the potential of the ground water in the study area. Based on information obtained from exploration wells, the next six test wells were constructed in which five wells constructed in layers of alluvium and one well in hard rock. Test wells in the alluvium has a depth ranging from 6 m to 13 m with a diameter of 254 mm and the test well in hard rock with a depth of 36 m with a diameter of 152 mm. The discharge from test well in hard rock was estimated less than 5 m³/hour during the drilling. However the test wells in the alluvial water discharges ranging from 28 m³/hr to 65 m³/hour. Generally, the drilling of the 100 mm diameter monitoring borehole encountered yellowish brown soft clay with some decaying wood fragments from the surface to a depth of 2.0 m, followed by dark grey medium grained sand up to a depth of 3.50 m. This is followed by dark grey fine grained sand with slightly clay up to 5.50 m, followed by dark grey medium to coarse sand and some dark grey silty to fine grained sand up to 7.20 m, followed by schist bedrock. A total of 35 units of 50 mm diameter shallow alluvium piezometers and two (2) units of 150 mm diameter shallow alluvium test wells were constructed along Linggi River riverbank. The Step Drawdown Test that was carried out on the exploration tubewell SL-TW 1 consists of 5 discharging steps, each step for duration of 90 minutes. The 4 discharging steps that were carried out were 5.5 m³/hour, 6.5 m³/hour, 7.5 m³/hour and 8.5 m³/hour. The initial static water level was at 1.30 m below ground level, and the final water level was at 2.83 m below ground level, with a total drawdown of 0.52 m. The Constant Discharge test was carried out at a rate of 7.96 m³/hour for the exploration tubewell SL-TW1. This is the maximum capacity of the submersible pump that was used for the pumping test. The initial static water during the Constant Discharge Test was 1.1 m below ground level and the final water level after pumping non-stop for 72 hours was 2.37 m, with a total drawdown of 1.27m. The transmissivity value is 1.37 m²/hour. The procedure for Recovery Test is for the water level in the pumped tubewell to achieve 80% recovery from its initial static water level. The Recovery Test was carried out for a total of 4.5 hours. The initial residual drawdown was 2.37 m, and the residual drawdown after 4.5 hours was 0.3 m, with a recovery of 76.38%. The transmissivity value for the Recovery Test is 18.21 m²/hour. Constant Discharge Test was performed on the test wells SL-TW2 to determine aquifer characteristics. During the pumping tests, drawdowns of the groundwater level were also measured at the nearby monitoring wells (SL-MW15, SL-MW14, SL-MW13, SL-MW12, SL-MW11 and JL13). After the constant pumping at a rate of 17.1 m³/hour for 72 hours, the final drawdown is 7.24 m with a total drawdown of 5.65 m. The total drawdown at the monitoring wells ranged from 0.69 m to 1.05 m. Based on this analysis, the hydraulic conductivity of the test wells SL-TW2 is 17.1 m/day, while for monitoring wells ranged between 54.1 to 63.1 m/day. The average of the hydraulic conductivity is 53.1 m/day. Transmissivity for the test well is 102 m²/day, while for monitoring wells ranged between 325 to 379 m²/day. The average value of the transmissivity is 319m²/day. The Recovery Test resumed immediately after the Constant Discharge Test was completed. The Recovery Test was carried out for a total of 120 minutes after the pump was shut down. For a period of 120 minutes after the pump is shut down, the remaining drawdown of the test well SL-TW2 is 0.2 m, while for monitoring wells ranged from 0.15 to 0.64 m. Based on this analysis, it was found that the hydraulic conductivity of the test well SL-TW2 is 16.7 m/day, while for monitoring wells ranged between 38.8 to 51.1 m/day. The average hydraulic conductivity value is 43.0 m/day. While the transmissivity value for the test well is 100 m²/day, and for monitoring wells ranged between 233 to 306 m²/day. The average transmissivity value is 258 m²/day. Based on Kozeny-Carman equation, the hydraulic conductivity is between 3.6 to 174.6 m/day with an average of 48.5m/day. Hydraulic conductivity values based on the Hazen are between 6.79 to 202.7 m/day with an average of 61.4 m/day. The values obtained are compatible with the results of grain size analysis carried out which showed that medium to coarse grained sand is the dominant size in the study area. The transmissivity, T values obtained from the Constant Test and Recovery Test ranged between 100 to 379 m²/day, with an average of 257 m²/day. Storage coefficient, S is obtained from discharge test equipment for pumping the test wells. The results of the analysis conducted found that storage coefficients ranged between 4.17x10⁻⁴ and 2.6x10⁻¹ with an average of 3.93x10⁻².

2.1.3 Muda River

The study area is located in the northwest state of Kedah and Pulau Pinang within the Muda River Basin, Peninsula Malaysia, and extends between RSO longitudes 100°29'0" to 100°33'30" Easting and latitudes 5°32'30" to 5°35'30" Northing and covers an area of 35 km² (Figure 1). The nearest town to the study area is Sungai Petani (Kedah) and Kepala Batas (Pulau Pinang). The Muda River has been developed as one of the most important water resources for agriculture and water supply for Kedah and Pulau Pinang. The three major tributaries of Muda River system are Ketil River, Sedim River and Chepir River. This location near to the residential and crops area. The Muda River is the longest river in the state of Kedah with its upstream flow coming from the northern mountainous area of the state. The river which has length of 180 km, flows towards the southern area of the state and has a catchment area 4210 km². Downstream, the river charges its course towards the west coast after passing the confluence of the mainstream and its largest tributary which is the Ketil River. The annual rainfall in the study area is about 2000-3000 mm. Both Kedah and Pulau Pinang have the rights to use the water from the Muda River. The Quaternary stratigraphy of the study area is divided into Beruas Formation and Gula Formation. The uppermost layer is the Beruas Formation consisting of Holocene terrestrial sediments of brownish color. Underlying the Beruas Formation is the Gula Formation. It is comprised of clay, silt, and sand with shells. The presence of the Gula Formation acts as an impermeable layer, thus confining other formations beneath it. This site was chosen for RBF study due to the high water demand in the area and groundwater is seen as one of the source with very high potential to be developed as supplementary source to meet the high public water supply demand. Fifteen monitoring wells and two test wells were constructed at the study site and pumping tests have been carried on these two test wells. The pumping tests indicated that TW1 were able to produce 43.92 m³/h and TW2 is about 51.609 m³/h during the duration of 72 hours pumping tests with drawdown 3.22 m and 1.88 m respectively. Water quality analyses were carried out from the Muda River and groundwater. From the study site showed decreased in turbidity, nitrate, aluminium and sulphate in groundwater. The study on the effectiveness of BI method in Muda River Basin, Pulau Pinang and Kedah shown that the water quality from BI is improved rather than river water quality and the quantity of water abstraction is high because depth of aquifer is about 30 m from ground level. The study was carried out to evaluate the hydraulic properties of the aquifer and riverbed and to determine the effectiveness of the BI at Muda River. Grain size analysis was conducted to identify the proportion of clay, silt, sand and gravel for both test well (TW). Based on the results of grain size analysis, the aquifer composed of fine to coarse grained sand with a mixture of gravel and higher moisture content down to the base of the aquifer system. The hydraulic conductivity of riverbed sediment based on grain size analysis is 80 m/day and the width of Muda River is 90 m to 130 m.

3 METHODOLOGY

3.1 Distance of RBF

The distance of RBF from the river to the study area was firstly considered following these two criteria:

- (i) The length of riverbank affected by a RBF system increases with the number of the applied wells and is expected to significantly influence yield. The more wells situated along the riverbank, the longer the reach of the river the aquifer gains recharge from runoff flow;
- (ii) Hydraulic connection extent between river water and groundwater. The feasibility of RBF is getting worse and may even be impossible with increasing distance from river. In order to get more complete background information on potential RBF sites, a large study area was recommended. According to the runoff quantity, the study range of RBF was divided along the river (Table 1). Where there is a surface water divide in the study range, this natural feature is used as the boundary of the study area.

Table 1. Type of surface runoff and distance of RBF to river.

Type	1	2	3	4	5
Surface runoff (m ³ /day)	>600	600-250	250-100	100-40	<40
Distance from river (m)	200	180	150	130	100

3.2 Evaluation index system

The aim of this research is to find potential suitable areas for future water development plans and further detailed investigation of RBF systems. The specific goal of RBF is mainly to provide sufficient water resources with good water quality. A multi-criteria RBF evaluation index system was established based on water quantity, water quality, the development and utilization conditions of groundwater resources and the interaction intensity between surface water and groundwater. The index weight and detailed scoring criterion were all based on specialist marking methods, which is more effective for a specific site but may not be applicable to other areas (Table 2).

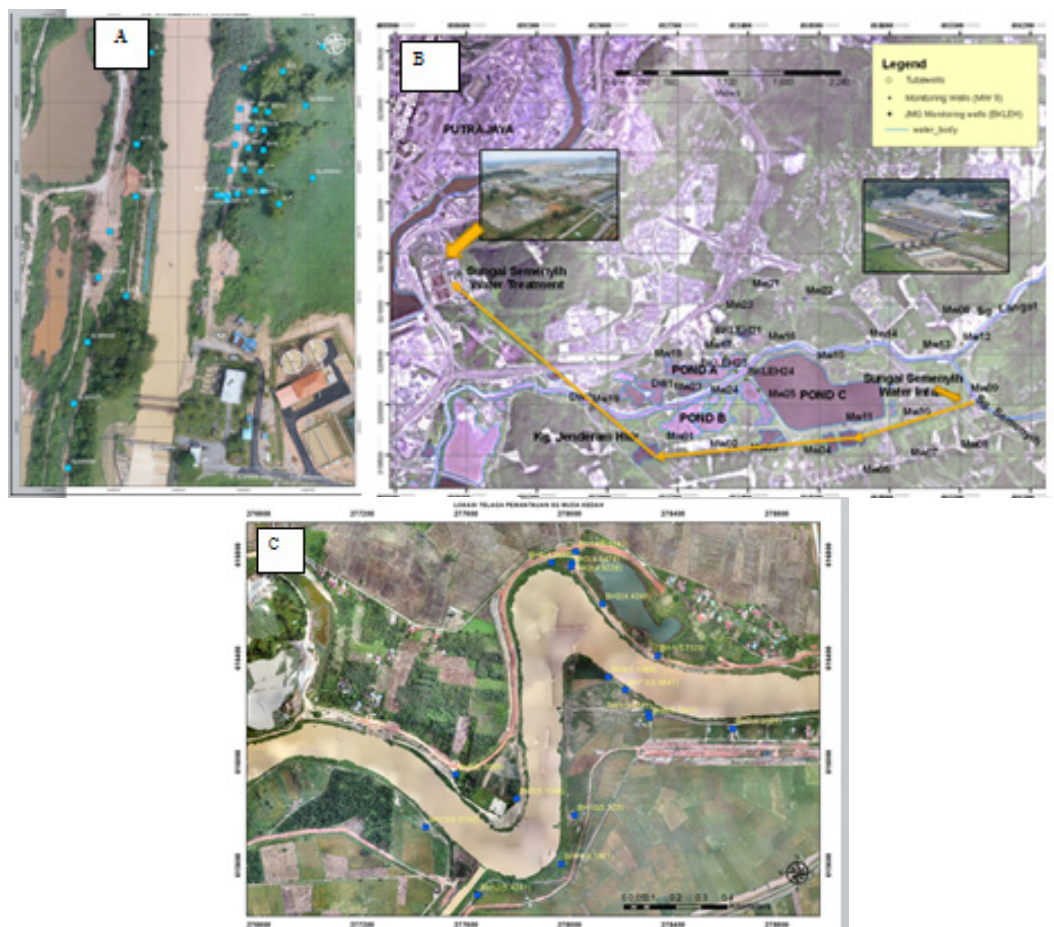


Figure 1. The location of the study area (A) Linggi River, (B) Langat River and (C) Muda River and the test wells and monitoring wells at the study area

Table 2. Evaluation index system and index weight.

Category of evaluation Index		Evaluation Index (X)	Index Weight (W)	
Water quantity	groundwater	Hydraulic conductivity (K)	0.10	0.30
		Aquifer thickness (M)	0.10	
Water quality	surfacewater	Runoff in cross section (Q)	0.10	0.30
	groundwater	Status of groundwater (G)	0.15	
	surfacewater	Status of surface water quality (S)	0.15	
Interaction intensity between surfacewater and groundwater		Groundwater hydraulic gradient (I)	0.10	0.30
		Possible influence zone width of surfacewater under the condition of groundwater exploitation (L)	0.10	
		Permeability of riverbed layer (R)	0.10	
		Groundwater Level (D)	0.10	
The exploitation condition of groundwater resource				0.10

The main reasons for index weight are explained as follows: (1) The sum of evaluation index weight is equal to 1 by value assignment. The index weight of water quantity, water quality and interaction intensity between surface water and groundwater each accounts for 0.3 of total weight individually, and this allotment reflected the aim and decisive factors of RBF suitability evaluation of the study site. The index weight of development and utilization conditions of groundwater resources only account for 0.1 of total weight, because the factor will influence groundwater development cost and help to confirm the priority, but it is not a decisive factor for RBF suitability evaluation; (2) For the index of water quantity, the groundwater index accounts for 0.20 and surface water index accounts for 0.1, because the water source of RBF waterworks comes from

riverside groundwater and surface water via bank filtration. Hydraulic conductivity and aquifer thickness influence the infiltration rate and capacity of surface water to aquifer; (3) For water quality, the index weight of groundwater and surface water are equal to 0.15. The groundwater quality only indicates the current status and treatment effect of RBF. In order to avoid any possible groundwater contamination from surface water, the treatment effect of RBF should not be addressed too much and the surface water quality should not be neglected; (4) The interaction intensity between surface water and groundwater controls the water exchange efficiency. Only those places within the influence zone of surface water, the aquifer prone to receiving sufficient water quantity through RBF, the permeability of riverbed layer controls the real water exchange rate and the groundwater hydraulic gradient partly reflects the real condition of aquifer property; (5) The index weight of groundwater depth accounts for 0.1, because it will only influence the priority order of potential RBF areas.

3.2.1 Water quantity

(1) Hydraulic conductivity (K)

Aquifer hydraulic conductivity (K) reflects lithology and permeability of an aquifer. The index value of hydraulic conductivity is shown in Table 3.

Table 3. Index value of hydraulic conductivity (K).

K (m/d)	>100	100-50	50-20	20-5	5-1	1-0.1	<0.1
Index value	100	90	80	70	60	30	0

(2) Aquifer thickness (M)

A suitable RBF site requires a certain scale of aquifer for adequate water production. The aquifer thickness index value is shown in Table 4.

Table 4. Aquifer thickness (M) index value.

M (m)	>50	30-50	10-30	5-10	3-5	1-3	<1
Index Value	100	90	80	70	60	30	0

3.2.2 Surface runoff (Q)

The larger the annual average surface runoff, the greater the recharge potential of surface water to groundwater, and the greater the potential suitability of the area for RBF. The surface runoff index values are shown in Table 5.

Table 5. Surface runoff index value.

Q (m3/day)	250-100	100-40	40-10	10-5	5-1	1-0.1	<0.1
Index value	100	90	80	70	60	30	0

3.2.3 Water quality for groundwater and surfacewater

Water quality status of surfacewater or groundwater directly reflects whether is suitable for drinking, and indicates the cost of water treatment that will produce drinking water. In order to guarantee the water quality of potential waterworks, the water quality improvement effect of RBF was thought of as an additional assurance. Because of limit element of parameter in water quality index for surfacewater and no water quality index for groundwater was developed, Environmental quality standards for surface water (GB3838-2002) (General Bureau of China National Environmental Protection, 2002) and Quality standard for groundwater (GB/T 14848-93) (Quality Standard for groundwater, 1993), water of quality grades I, II and III can be used as drinking water directly. Water of quality grade IV must be treated before it is supplied for drinking. Because higher index values of the quality grade indicate lower quality water, the assigned index values decrease as water quality grades change from I to IV. Water of quality grade V is a negative factor for the suitability of RBF, and its index value is assigned a negative number. This can make the negative water quality factor play a decisive role in the process of suitability evaluation of RBF. The groundwater quality (G) and surface water quality (S) suitability scoring criterion is shown in Table 6.

Table 6. Groundwater quality (G) and surface water quality (S) index value.

G/S	I	II	III	IV	V and Worse than V
Index Value	100	95	90	60	-275

3.2.4 Interaction intensity between surface water and groundwater

A large proportion of RBF waterworks primarily capture surface water; the interaction intensity between surface water and groundwater plays an essential role. Hydraulic Gradient (I) under the Current Condition The

hydraulic gradient directly reflects recharge-discharge relationship between surface water and groundwater, and it also indicates recharge-discharge conditions of the interaction zone. A positive hydraulic gradient was defined to represent scenarios in which river water recharges groundwater; similarly, a negative hydraulic gradient indicates that river water is recharged by groundwater. A positive value of hydraulic gradient is beneficial to RBF in most situations; however, a very large value for the hydraulic gradient might mean that riverside groundwater is being exploited intensively or that the interaction between surface water and groundwater is poor, because the very low permeability of aquifer or riverbed will obviously enlarge hydraulic gradient and decrease water exchange intensity. A negative hydraulic gradient indicates that the surface water cannot be induced into the ambient aquifer at present. Nevertheless, a negative gradient might be reversed and to be beneficial for RBF under groundwater exploitation condition. If the present negative hydraulic gradient is excessively small, it may indicate that the permeability of aquifer or riverbed is very poor, and the large groundwater recharge potential from river water should not be expected under any exploitation conditions. The hydraulic gradient suitability scoring criterion is shown in Table 7.

Table 7. Hydraulic gradient (I) suitability evaluation criteria.

I	>10	10-5	0-5	0 to -5	-10 to -5	<-10
Index value	40	80	100	90	80	60

3.2.5 Influence zone width of surface water under the condition of groundwater exploitation (L)

The influence zone by surface water indicates the range of the hydraulic connection between surface water and groundwater. The greater the hydraulic connection range between surface water and groundwater, the superior the RBF site. The possible influence zone (L) was assumed to be equal to the ratio of the aquifer thickness (M) to the hydraulic gradient (I). The suitability index value for the possible influence zone by surface water is shown in Table 8.

Table 8. Index value for the possible influence zone width of surface water under the condition of groundwater exploitation (L).

L	$\frac{M}{ I _{max}}$	$\frac{M}{ I _{max}}$ to $\frac{M}{ I _{average}}$	$\frac{M}{ I _{average}}$ to $\frac{M}{ I _{min}}$	$\frac{M}{ I _{min}}$
Influence intensity index value	Strong 100	Medium 80	Weak 60	None 30

3.2.6 Permeability of riverbed layer (P)

Riverbed permeability indicates the exchange capacity between surface water and groundwater. Riverbed permeability is calculated using the hydrogeological cross section of the riverbed obtained from a field investigation as standard. Then, the lithology under the riverbed is analyzed to obtain its permeability, either by measurement or practical experience. The riverbed permeability suitability index value is shown in Table 9.

Table 9. Permeability of riverbed layer (R) suitability scoring criterion.

P (m/d)	>5	1-5	0.5-1	0.1-0.5	0.05-0.1	0.01-0.05	<0.01
Index value	100	90	80	70	60	30	0

3.2.7 Groundwater level

When considering the development and utilization of groundwater resources, groundwater level is a primary concern because it indicates the cost of building RBF wells. If the groundwater level is too far below the ground surface, it may be in a highlands area or in a cone of a groundwater depression. In those places, the extraction of groundwater requires more energy. The groundwater level index value is shown in Table 10. Because groundwater level is strongly influenced by regional characteristics, this standard should be adapted to different hydrogeology conditions.

Table 10. Groundwater depth (D) index value.

D (m)	<5	5-10	10-15	15-20	20-25	25-30	>30
Index value	100	90	80	70	60	30	15

3.2.7 Suitability Index

According to the evaluation index system created above, the complex suitability index for a potential RBF site can be calculated by weighted summation using Eq. [1].

$$A = X_K \times W_K + X_M \times W_M + X_Q \times W_Q + X_G \times W_G + X_S \times W_S + X_I \times W_I + X_L \times W_L + X_R \times W_R + X_D \times W_D \quad [1]$$

In Eq. [1], A is the suitability index of a potential RBF sites, X is the index value of individual indices as defined in Tables 3–10 and W is the weight of each corresponding index as defined in Table 2. The RBF suitability was then classified into five grades according to the suitability index value (Table 11).

Table 11. RBF suitability class.

Suitability Index Value	Class	Suitability Evaluation
90-100	I	Excellent suitable areas
80-89	II	Good suitable areas
70-79	III	Moderate suitable areas
60-69	IV	Poor suitable areas
<60	V	Unsuitable areas

In areas for which RBF suitability grades are between I and III, water quality satisfies human drinking water requirements and does not need treatment, and water quantity is adequate. Furthermore, the exchange between river water and groundwater is intensive, the water quantity and water quality of RBF is guaranteed, and there are good development and utilization conditions of groundwater resources. In short, areas in grades I–III are suitable for RBF. In areas for which the RBF suitability grade is IV, either water quality does not satisfy drinking water requirements directly or the water recharge is insufficient. After water treatment and limited exploration, such areas may be suitable for limited-scale RBF waterworks. Areas in grade V are unsuitable for RBF works because of unacceptable water quality, high water treatment costs or insufficient water recharge to sustain extraction at the required rate and volume.

4 RESULTS AND DISCUSSIONS

The various index values were integrated using Eq. [1] to determine the overall suitability of locations at the study area for RBF works. Nine typical points were selected to show the characteristics of each class of suitability (Table 12). Based on the multi-criteria analysis, the suitability of many locations in the study area was classified as grade I and II and should be suitable for locating RBF works.

Table 12. All single index values and scores for three sites.

Index	Muda River		Linggi River		Langat River	
	Value	Index Value	Value	Index Value	Value	Index Value
K, hydraulic conductivity	80 m/d	90	53.1	80	63.64 m/d	90
D, Aquifer thickness	17.9 m	80	7.5	70	17.1	80
R, surface runoff	432x10 ⁴ m ³ /day	100	518 x 10 ⁴ m ³ /day	100	164 x 10 ⁴ m ³ /day	100
G, Groundwater quality	III	90	II	95	II	95
S, Surfacewater quality	II	95	III	90	III	90
I, Hydraulic gradient	-0.2	90	-0.1	90	- 0.035	90
W, Influence zone	strong	100	strong	100	strong	100
P, Permeability of riverbed layer	1.9 m/d	90	0.3 m/d	70	1.2 m/d	90
D, groundwater level	2.2	100	2	100	1.6	100
Total Index value		92.80		88.33		92.80
Class		I		II		I

5 CONCLUSIONS

Many important factors affect the site selection for RBF works such as groundwater and surface water quantity, current water quality situation, hydraulic interaction degree and exchange relationship between groundwater and surface water. In this research, a multi-criteria index system was developed for assessment of RBF site suitability. The RBF index system was based on a detailed analysis of physical geography and geological and hydrogeological conditions (which were considered to be the main influential factors of RBF), as well as on the development and utilization of water resources and water demand. Value index criteria based on specialist marking methods were used to determine weighting coefficients and weighted scores. The evaluation method was integrated will put into the spatial analysis features of GIS to determine the distribution of suitable areas for RBF works. However, this research still has some limitations that must be mentioned here and will be studied further.

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