REMOVAL OF SOLIDS, TOTAL COLIFORM, E.COLI, UV254, COLOUR AND TURBIDITY USING LIMESTONE FILTER IN RIVERBANK FILTRATION

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By

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ABSTRAK

Perbandaran pesat dan pertumbuhan penduduk di Malaysia telah membawa kepada peningkatan permintaan air yang tinggi. Ia juga menyebabkan peningkatan dalam tahap pencemaran, terutamanya kepada jasad air yang bertindak sebagai sumber bekalan air. Penggunaan sistem penapisan tebing sungai (RBF) sebagai kaedah pra-rawatan di loji rawatan air telah menjadi semakin penting dalam beberapa tahun kebelakangan ini. Disebabkan proses peyingkiran semula jadi penapis dan penyerapan oleh pelbagai jenis media penapis, RBF mempunyai potensi yang cerah untuk digunakan sebagai penapis bahan cemar. Dalam kajian ini, batu kapur digunakan sebagai media penapis dalam sistem RBF skala makmal. Ciri-ciri fizikal dan kimia batu kapur telah ditentukan terlebih dahulu sebelum dan selepas eksperimen dengan menggunakan kaedah pengimbasan mikroskopik pengimbasan (SEM) dan X-Ray Fluorescence. Dua rentang saiz batu kapur, 1.18 mm-2 mm dan 2.36 mm- 4.75 mm digunakan sebagai media berliang dan sampel air diambil dari Sungai Kerian, Lubok Buntar, Perak sebagai tapak kajian kes. Kecekapan penyingkiran parameter air terpilih iaitu pepejal terampai, jumlah coliform, *E. coli*, UV_{254}, warna dan kekeruhan ditentukan dalam tempoh 15 hari eksperimen. Saiz zarah dan morfologi media juga ditentukan dengan menggunakan kaedah SEM. Keputusan SEM ini, ia menunjukkan bahawa kapur terdiri daripada belahan rhombohedral dan gabungan kristal saiz mikron bersama-sama dengan saiz liang kecil. Batu kapur yang digunakan dalam kajian ini adalah dari jenis kalsit. Kalsit mengandungi 52.93% kalsium oksida (CaO) dan 0.66% magnesium oksida (MgO). Hasil daripada kajian turus menunjukkan bahawa penyingkiran zarah dan jumlah pepejal terlarut (TDS) tidak dapat ditentukan kerana larutan batu kapur yang terlepas sebagai tapisan. Batu kapur dengan saiz 1.18mm-2.0mm dan 2.36mm-4.75mm menunjukkan perbezaan ketara dalam

kecekapan penyingkiran jumlah coliform, pepejal terampai, *E. coli*, kekeruhan, UV_{254} dan warna. Kesan penyingkiran yang diperolehi untuk parameter pepejal terampai (SS) , jumlah coliform, *E. coli*, UV_{254}, warna dan kekeruhan adalah masing-masing 91% -97%, 82% -93%, 93% -98%, 28% -40% , 60% -83% dan 78-83%, bagi kedua-dua turus. Tiada terobosan yang diperhatikan dalam tempoh 15 hari eksperimen. Batu kapur yang bersifat alkali telah meningkatkan nilai pH dari 6.19 sebelum tapisan kepada 6.53 dan 6.57 efluen untuk kedua-dua turus.

ABSTRACT

The rapid urbanization and growth of the population in Malaysia have led to increase demand for water. It has also caused an elevation of pollution level, especially in water bodies which acts as a water source. The use of riverbank filtration system (RBF) as pre-treatment method in the water treatment plant has become a common interest in recent years. Due to natural attenuation process of filtration and sorption by various types of filter media, RBF has high potential to filter contaminants. In this study, limestone was used as a filter media in a laboratory scale RBF system. The physical and chemical characteristics of limestone were first determined before and after the experiment by using scanning electron microscopy (SEM) and x-ray fluorescence (XRF) methods. Two difference ranges of limestone sizes, 1.18 mm-2 mm and 2.36 mm- 4.75 mm were used as a porous media and the sample of water was taken from Sungai Kerian, Lubok Buntar, Perak as a case study site. The removal efficiencies of selected water parameters namely suspended solids, total coliform, *E. coli*, UV_{254}, colour and turbidity were determined within 15 days of the experiment. The sizes of particles retained and the morphology of media were also determined by using particle analyzer and SEM machine, respectively. From the SEM results, it showed that the limestone was made of rhombohedral cleavage plane and the combination of micron-size crystal along with the small size of pores. The limestone used in this study was mainly made up of calcium carbonate ($CaCO_3$) and categorized as calcite. The calcite contains 52.93% of calcium oxide (CaO) and 0.66% of magnesium oxide (MgO). The result from the column study showed that the removal of particles and total dissolved solids (TDS) using limestone could not be determined due to the leaching of limestone which added the impurities into the water. Limestone with size 1.18mm-2.0mm and 2.36mm-4.75mm did show a

significant difference in the removal efficiencies of total coliform, suspended solid, *E. coli*, turbidity, UV_{254} and colour. The removal efficiencies obtained for the following parameters suspended solids (SS), total coliform, *E. coli*, UV_{254}, colour and turbidity were 91%-97%, 82%-93%, 93%-98%, 28%-40%, 60%-83% and 78-83%, respectively for both column. No breakthrough was observed within 15 days of the experiment. The addition of limestone has increased the pH of the water sample from 6.19 before filtration to 6.53 and 6.57 for the final pH at effluent in column 1 and column 2 respectively.

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LIST OF ABBREVIATIONS

ASTM	American Society For Testing And Materials
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
SS	Suspended Solids
NWQS	National Water Quality Standards
RBF	River Bank Filtration
EBCT	Empty Bed Contact Time
SEM	Scanning Electron Microscopy
HLR	Hydraulic Loading Rate
SMEWW	Standard Methods for the Examinations of Water and Wastewater
USEPA	United States Environmental Protection Agency
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
TDS	Total Dissolved Solids
XRF	X-Ray Fluorescence
MUG	4-Methylumbrelliferyl-b-D-Glucuronide
ONPG	Ortho-Nitrophenyl-ß-Galactoside

NOMENCLATURES

A	Cross sectional area
A_{eff}	Effective cross sectional area
D	Diameter
ε	Empty volume percentage
H	Adsorbent height
Q	Flow rate
V	Adsorbent volume
$V\varepsilon$	Empty volume
Vw	Volume of water

CHAPTER 1

INTRODUCTION

1.1 Background

The rapid urbanization and growth of the country's population has led to increase demand for water consumption and water pollution level in Malaysia. The rapid development has produced large volumes of human waste included the domestic, industrial, commercial and transportation wastes. Total internal water resources of Malaysia are estimated at 580 m^3/year (Food and Agriculture Organization, 2011). Malaysia receives abundant rainfall averaging 3,000mm annually that contributes to an estimated annual water resource of some 900 billion cubic metres. About 97% of the raw water supply for the domestic use, agriculture and industrial activities comes from the primarily river water (WWF, 2008). However, continuous urbanisation and industrialisation have caused a large number of polluted rivers, especially in urban areas. Hence, with the increasing demand for piped drinking water, river water protection is important for attaining the sustainable access in providing a safe and clean water to the communities.

The sources of water pollution may come from human activities such as dumping of industrial effluents, sewage, agricultural waste, and domestic wastes. Waste dumped on lands, such as animal dung, litter, and wind-deposited pollutant etc., also contribute to water pollution (Maitera et al., 2010). Surface water with extreme values of pH, low levels of dissolved oxygen (DO), raise in temperature, total dissolved solids (TDS), conductivity, colour, ammoniacal nitrogen (NH_3-N), chemical oxygen demand (COD), biological oxygen demand (BOD), suspended solids (SS), total coliform, *E. coli*, turbidity in water indicate that the pollution have taken place in many water bodies (Hamdan et al., 2013).

In Malaysia, water can be treated with the conventional treatment method such as pre-treatment, coagulation and flocculation, sedimentation, dissolved air flotation, filtration, disinfection and others (Somasani, 2012). The degree of treatment depends on the nature of the water source. The conventional treatment method is found suitable and cost-effective for the water source that falls within Class I and II as tabulated in the National Water Quality Standard (NWQS) of Malaysia (Zainudin, 2010). Thus, riverbank filtration (RBF) system may be utilized as a pre-treatment technique in areas with polluted water bodies. The filtration works by passing water meant to be purified through the banks of a river or lake which are then drawn off by extraction wells. Due to natural attenuation process of filtration, sorption and etc., RBF has high potential to filter contaminants. Therefore, RBF can be classified as a low-cost and efficient pre-treatment method for potable water abstractions (Abd Rashid et al., 2015). It can effectively remove many major pollutants and micro pollutants including particulates, colloids, algae, organic and inorganic compounds, micro-cystins, pathogens and even heavy metals (Schmidt at el., 2003a). RBF is an efficient and low-cost natural alternative technology for water supply application in which surface water contaminants are removed or degraded as the infiltrating water moves from the river to pumping wells (Hamdan et al., 2013). RBF systems can significantly reduce the concentrations of many surface-water pollutants (Dalai and Jha, 2014).

The effectiveness of riverbank filtration system treatment is determined based on the physical characteristics of river water and type of media used as the filter. Limestone has been proven effective in removing heavy metals from water and wastewater has been investigated by many researchers (Affam and Adlan, 2013; Abdul Aziz et al., 2004; Hussain et al., 2011; Labastida et al., 2017; Wang et al., 2013). It has the capacity in removing heavy metals such as Cu, Zn, Cd, Pb, Ni, Cr, Fe and Mn through a batch process using the filtration technique

(Labastida et al., 2017). Hence, limestone filtration media has potential to be applied as filter media in RBF system as it is a cost-effective and eco-friendly (Abdul Aziz et al., 2008).

1.2 Problem Statement

During extended dry seasons, many Malaysian consumers are face potable water crisis. Furthermore, the crisis is worsening by the increasing number of polluted rivers in our country which drastically decrease the number of available clean water sources to the consumers. Due to this problem, there are several proposals to switch to partial usage of groundwater as a supplementary water resource. However, the continuous and excessive pumping of groundwater resource will become a great pressure on a natural aquifer and will eventually lead to abstraction beyond its capacity. Based on the study, several countries have utilized riverbank filtration (RBF) system as pre-treatment technique in order to meet the demands for water since water is needed in huge quantity in a short time. Further, the transition of shallow groundwater will be flushed away during the rainy season. There are limitations in different RBF systems especially on the type of media used which require specific modification to improve the treatment facilities. Thus, to sustain the RBF system more efficient and economically feasible alternative media is looked for the treatment method. In this study, limestone was investigated as artificial barrier for the removal of particles, total coliform, *E. coli*, total dissolved solids (TDS), suspended solids (SS), UV_{254}, colour and turbidity in river water through RBF.

1.3 Objectives

The main objectives of this research are as follows:

i. To determine the physical and chemical characteristics of the limestone as an adsorbent in an RBF system.

ii. To replicate a filtration system that resembles the RBF system and to evaluate the capacity of limestone as an absorbent.

iii. To analyze the removal performance of solid, total coliform, *E.coli*, UV_{254}, colour and turbidity using limestone filter in river water in a column test.

1.4 Scope of Work

The study focuses on the removal performance of solids, total coliform, *E. coli*, UV_{254}, colour and turbidity using limestone in column study. Water characteristics study was carried out to determine the physical and biological contaminants of river water from Sungai Kerian, Lubok Buntar as a case study site. The column study was carried out using limestone as a porous media to remove the contaminants from the water samples. The removal efficiencies were determined by comparing the concentration of selected parameters before and after the column test.

1.5 Dissertation Outline

This dissertation contains five chapters:

Chapter 1 explains briefly the background, problem statement, objectives and scope of this study. It gives an overview of the study.

Chapter 2 discusses the literature review about riverbank filtration, mechanisms in porous media, composite adsorbent (limestone), river water quality study and limestone removing performance.

Chapter 3 covers the methodology used in this research. It includes preparation of limestone media, limestone characteristic study, river water sampling, river water characterization, column test using limestone, column adsorption parameter, influent and effluent measurement, and control test.

Chapter 4 presents the results obtained from the experimental works. The results are presented in graphical form and analysis and discussion are made in detail.

Chapter 5 concludes the findings of the research and provide recommendations for improvement in future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Water pollution is a significant problem in Malaysia and impacts negatively on the sustainability of water resources (WWF-Malaysia, n.d.). In addition, it also affects plants and biological organism, people's health and the country's economy. It reduces total water availability considerably, as the cost of treating polluted waters is too high and in some instances, polluted waters are untreatable for consumption. The sources of water pollution may come either in form of a point or non-point sources that affect the river water quality and contribute to the increase of the organic and inorganic contaminants, temperature and pathogens in the natural water body. The total availability of water decreased because the treatment of raw water from the surface water sources for human consumption and industrial use had become more convoluted and costly and not treatable for consumption. (Afroz et al., 2014).

In Europe, riverbank filtration (RBF) is a natural process of water treatment technology which has been used for many years for drinking water. It is cost effective, natural pre-treatment technology of surface water and groundwater to supply drinking water to the communities along the Rhine, Elbe, Danube, and Seine rivers (Kuehn and Mueller, 2002)

There are many RBF system for certain function. For example in India, the RBF barrier was made for hydraulic barrier by channelling to a drain. Unlike in Poland, the barrier is applied to control the contaminant from passing through into abstraction well by constructing a barrier upstream of the well. These show that the main purpose of all barriers are to control the quality of riverbank filtered water (Abd Rashid et al., 2015). These cases indicate that it is important to design and implement an artificial barrier in order to sustain the RBF system. Thus, the study on this artificial barrier should not only focus on the development of RBF but also how to improve specific water quality parameter and soil hydraulic conductivity.

Riverbank filtration (RBF) is a type of filtration processes that functions by allowing water to be purified for commercial uses through banks of a river. Compared to the recent conventional water treatment process, RBF consist of natural processing steps of water treatment. The common technology applied in this process is by means of the aquifer within unconsolidated material deposited by water which typically presents adjacent to the rivers (Nordin et al., 2016). Riverbank filtrate includes both groundwater and river water that has percolated through the riverbank or riverbed to an extraction well.

2.2 Riverbank Filtration (RBF)

Riverbank filtration (RBF) has been a common practice in many European cities, most notably along the river of Rhine, Elbe and Danube, to produce drinking water for more than 100 years. It was originally initiated to remove pathogens and suspended solids from increasingly polluted surface waters. It is a natural water treatment technology, where surface water is infiltrated to an aquifer through river or lake banks. Enhancement of water quality is achieved by a series of chemical, biological and physical processes during subsurface passage (Sprenger et al., 2011).

RBF can potentially reduce or stabilise the microbial, natural organic matter and particulate load. It makes drinking water safer and more acceptable for the consumer, but not all undesired substances can be removed during soil and aquifer passage. It also prevents from shock loads and assures the removal of particles, biological contaminants and biodegradable compounds allows for temperature adjustment (Schmidt et al., 2003b).

2.2.1 Classification of Riverbank Filtration (RBF)

The performance of an RBF system may be affected based on the following parameters; i.e., available river water that can be induced to flow into the aquifer, quality of river water, commercial river traffic such as a source of pollution, flow velocity, bed load characteristics, seasonality of river flow and the stability of the river channel (Ray et al., 2003)

There are two types of riverbank filtration process, natural RBF and forced RBF. Natural RBF happens when the percolation takes place based on the head differences or hydraulic gradient between the groundwater and the river (Caldwell, 2006). In forced RBF, the pumping action caused the effective stress and the water is bound to enter the soil matrix (Ojha et al., 2011).

The treatment effectiveness of RBF depends on a combination of several applicable processes such as clogging of the riverbed, the dilution with groundwater after infiltration, subsurface filtration (filtration, adsorption, biodegradation, ion exchange, oxidation/reduction) and additional treatment steps (Dalai and Jha, 2014).

2.2.2 Treatment system by RBF

RBF generally occurs in alluvial valley aquifers, which are the complex hydrologic system that exhibit both physical and geochemical heterogeneously. In most alluvial valley aquifers, sand and gravel are governed, but floodplain deposits leave the layers of silts and clay in the stratigraphy (Tufenkji et al., 2002). However, the ideal condition usually includes the coarse-grained, permeable water-bearing deposits that are hydraulically connected with the bed materials (Ray et al., 2003).

During the RBF process, physical and biochemical processes such as dilution, sorption, ion exchange, natural attenuation by microorganisms, filtering, and other chemical reactions can enhance groundwater quality by reducing physical materials (turbidity and microscopic particles), chemical components (dissolved organic carbon, pesticides, synthetic organics, pharmaceutical compounds, nitrate, dissolved ions, and metals), and biological contaminants such as protozoa, bacteria, and viruses (Ray, 2001).

The riverbed sediments may act as an effective filter medium in removing various water contaminants, the development of the reduced zone can be detrimental to the quality of bank filtrate. At a certain distance from the river's edge, where microbial activity diminishes as a result of a deficiency in electron donors and the aquifer is re-aerated, the reducing conditions decrease with intensity. Manganese and iron can then be removed from the solution by a series of precipitation reactions. Hence, the breadth of the reduced zone can be determined by considering the evolution of manganese and iron along the infiltration flow path. The location of this zone, however, may exhibit spatial and temporal variability due to seasonal fluctuations in microbial activity and water pumping patterns in the field (Shamrukh, 2014). The schematic diagram of riverbank filtration (RBF) processes is shown in Figure 2.1.

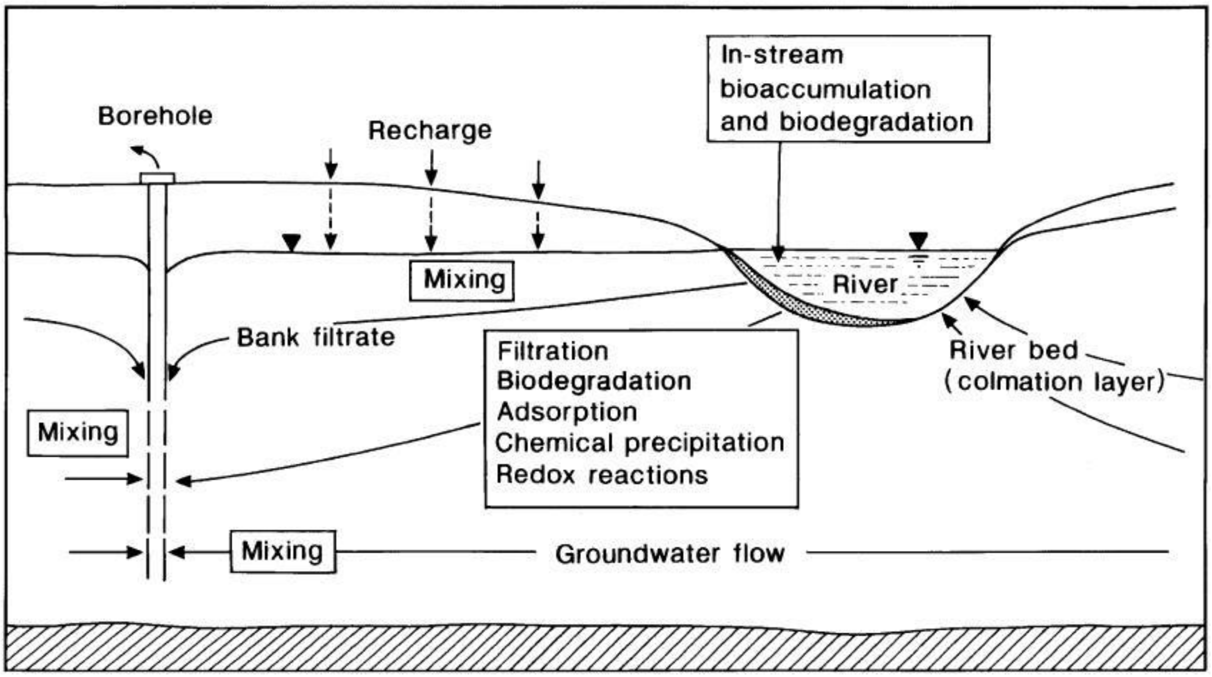

Figure 2.1: Riverbank filtration processes. (Source: Hiscock and Grischek, 2002)

Three pilot projects of RBF facilities were constructed in the states of Selangor, Perak and Kedah to analyse the quality of bank-filtered water in terms of turbidity and *E. coli* removal. The removal of biological contaminants using RBF can become more efficient if the groundwater velocity is slow and when the aquifer consists of granular materials with high grain surface contact. Many organic micro pollutants can be reduced or even eliminated during both aerobic and anaerobic underground passages (Adlan et al., 2016).

2.2.3 Advantage of Filtration (RBF) Treatment System

There are many advantages of RBF as reported by Smith (2010). It includes natural pre-treatment through riverbank filtration, reduced chemical usage for pre-treatment and resistance to contaminant threats. It has minimal colour, odour, turbidity and algae, features a low profile and is aesthetically pleasing. The technology decreases construction and operation costs, offering the lowest costs among supply options, and it provides maintenance cost savings (e.g., no leaf debris, which is common to surface water intakes). It reduces the need for disinfection, less sludge generation, achievement of treatment removal credits used to meet the Long-Term Enhanced Surface Water Treatment Rule, easy maintenance and consistent water quality and temperatures. It is also not susceptible to invasive plant infestation and has no impact on fisheries.

Due to its easy implementation and little maintenance requirements, RBF is considered to be a useful drinking water pre-treatment method for developing and newly industrialized countries. RBF systems are particularly known for the efficient removal of pathogens, suspended solids, toxic algae, or organic trace compounds (e.g. pharmaceutical products) from surface water, all being water quality parameters of high relevance (Tratschin and Spuhler, 2018).

Other than that, pre-treatment through bank filtration can remove suspended solids, organic pollutants, microorganisms, heavy metals and nitrogen. The RBF technology offers natural treatments, low cost, reduce the chemical used in pre-treatment processes and resistance to the contaminant threats (Amy, 2007; Bertelkamp et al., 2014). The water contaminant removal mechanisms and efficiency in RBF are summarized in Table 2.1.

Table 2.1: Summary of water contaminant removal mechanisms and efficiency in RBF. (Source: Sprenger et al., 2011)

Water quality Parameter			Removal process	Travel time or travel distance/redox state	Purification capacity of BF	Comments	Overall removal efficiency	Reference
Physico-chemicals		Suspended solids	Straining, Van-der-Walls forces	<10 days/-	<1 NTU	High capacity to remove suspended solids.	Good	Wang,2003;Schubert 2002
		DOC	Biodegradation, sorption	10 to 50 days/oxic	20 to 60%	Most efficient removal in the oxic infiltration zone, anoxic/anaerobic carbon degradation requires long travel time.	Good	Gruenheld et al., 2005;Miettinen et al.,1996
	Nutrients	Nitrogen	Nitrification, denitrification, sorption, annanmox, mineralization, assimilation			Nitrogen turnover strongly depends on redox conditions.	Moderate	Bohlke et al., 2006; Ray et al., 2002a, 2002b
	Inorganic	Pb, Cu, Zn, Cd, As, Fe, Mn, Se, Cr, U, F	Sorption, precipitation and ion exchange		0 to 94%		Inconsistent	Schmidt et al., 2003
Biological	Pathogens	Protozoa	Straining, inactivation, die-off	<10 days/-	0.5 to 4 log10	Straining only significant for protozoa.	Good	Berger, 2002; Tufenkji et al., 2004
		Bacteria	Sorption, die-off	11 to 63 days/-	3.2 to >5log10		Good	Dash et al., 2008; Schijven, 2002
		Virus	Sorption, inactivation	13 to 43 days/-	3.9 to 7.8 log10	Most efficient removal in the infiltration zone.	Good	Schijven et al., 2003; Havelaar et al., 1995
	Cyanotoxins	Microcystins	Straining, biodegradation	Few cm/oxic	2 to 3 log10		Good	Greutzmacher et al., 2009

Water quality Parameter			Removal process	Travel time or travel distance/redo x state	Purification capacity of BF	Comments	Overall removal efficiency	Reference
Micro pollutants	Organics	Pesticides	Degradation, sorption	Few cm/oxic			Inconsistent	Schwarzenbac h et al., 1983; Verstraeten et al., 2003
		Pharmaceuti cals	Degradation	Few m/oxic			Inconsistent	Heberer et al., 2004; Massmann et al., 2008
		Hydrocarbon s	Degradation	Few m/oxic	0 to 90%	Most efficient removal in the infiltration zone.	Inconsistent	Juttner, 1999; Schwarzenbach et al., 1983
		Endocrine Disruptor Compound	Degradation	Few m/oxic		90% Bisphenol A, estradioles, nonylphenols and octylphenols removed.	Moderate	

2.2.4 Limitation of Riverbank Filtration (RBF) Treatment System

Although riverbank system has many benefits, there are also some limitations to the system such as the high organic pollution and higher temperature which tends to promote microbial growth and lead to oxygen depletion and thus lowering the removal efficiency of the system (Huelshoff et al., 2009). Other than that, it also enhances clogging of the infiltration zone is likely to be observed with high levels of suspended solids especially in equatorial countries that may render the RBF unsustainable (Huelshoff et al., 2009). Lastly, polar, persistent organic substances are often not completely removed during underground passage dependent on residence time, length of subsoil passage, redox status (Schmidt et al., 2003a)

Schmidt et al., (2003b) reported that riverbed clogging was overcome by massive ground loosening. With the construction of artificial ditches and side channels further infiltration zones were created. To improve water quality and to achieve easier cleanabilities of infiltration zones, a specific sand layer was later incorporated in percolation ditches, channels, and ponds. A further stage of development was finally the construction of recharge basins similar to those found in nearly all artificial groundwater recharge plants nowadays. In these recharge basins, raw water is passed through a filtering medium that consists of a layer of sand. Operation of recharge and water catch at a longer distance from the riverbed results in systems that are widely unaffected by riverbank filtrate interference.

Based on Ibrahim et al., (2015), the disadvantage of this treatment is increased of heavy metal concentration. Several metals, such as As, Fe, and Mn, exceeded the permissible limit stated by the set standard.

Hu et al., (2016) stated that the capacity of RBF systems is limited by local hydraulic and hydrogeological conditions, which may not be favourable for the desired system performance. Although RBF system effectively removing the contaminant, the purification capacity of RBF system does not satisfy the primary standard of water treatment when the water pollution incidents occur thus increase treatment difficulties for waterworks due to the weakness of hydraulic connection between groundwater and surface water.

Lastly, based on the study by Jaramillo (2012), the efficiency and performance of RBF can also be compromised by scouring processes carried out on the river bed and banks when the flow rates are very high. The subsequent loss of fine sediments that responsible for the low permeability of the river bed could be a problem in the treatment process in such cases, since the efficiency of filtration decreases. Another effect of scouring is the removal of microorganisms which are essential for improving the quality of river water in the hyporheic zone, the transition zone between surface water and groundwater in the alluvial aquifer.

2.3 Mechanism in Porous Media

Most RBF systems are constructed in alluvial aquifers along riverbanks that consist of a variety of deposits ranging from sand, to sand and gravel, to large cobbles and boulders. The treatment effectiveness of RBF results from a combination of several applicable processes such as clogging of the riverbed, the dilution with groundwater after infiltration, subsurface filtration (filtration, adsorption, biodegradation, ion exchange, oxidation/reduction) and additional treatment steps (Dalai and Jha, 2014). In riverbank filtration, the mechanisms in the porous media include combinations of straining, adsorption and biodegradation (Ray et al., 2003).

In physio-chemical treatment, adsorption is defined as the sum of electrostatic, hydrophilic and steric interactions between the pollutant and the media (Aronino et al., 2009). RBF is a comprehensive process that involves straining, inactivation, sedimentation in pores and colloidal filtration (Hu et al., 2016). The removal mechanism is the combination of biological, physical and chemical mechanisms which may include the specific mechanism such as biological action, attachment of microbes to filter media by the electrochemical force and physical straining (Maung and Han, 2006). Straining is a physical removal process that depends on the size of the pore and the size of microbial particles which is influenced by the physical properties of the filter media and water such as grain size, amount of filter clogging and the content of the particles in the water which could trap in down gradient smaller pores that allow only small to pass (Bradford et al., 2002)

2.4 Composite Adsorbent (Limestone)

Limestone is a sedimentary rock, which is primarily composed of the mineral calcium carbonate ($CaCO_3$). Limestone acts as an adsorbent in heavy metal removal. The most commonly used limestone is calcite and dolomite. Limestone in a pulverized form is typically used. Commercially available limestone is pulverized and then sieved so that smaller particles with the enhanced surface area are produced. Adsorption using limestone is found to be economic, efficient and eco-friendly since it produced no harmful products (Silva et al., 2010).

As a result of the effectiveness of limestone in various treatment processes, it has been used for removal of contaminants from leachate. There is 100% removal of iron from leachate in 150 min during batch experiments in which limestone was used as a filter medium to treat an iron acid solution (27.9 mg/L iron). Limestone is capable of removing 90% of heavy metals such as Cu, Zn, Cd, Pb, Ni, Cr, Fe and Mn through a batch process and filtration technique (Labastida et al., 2017).

Other than that, different sizes of limestone roughing filter have been evaluated to remove turbidity, suspended solids, BOD and coliform organism from the wastewater (Maung, 2008). Limestone is a low cost treatment technology, eco-friendly and has great potential importance for heavy metal removal is used as filter media in the filtration process that will reduce select metals to below drinking water standard (Somasani, 2012).

2.5 River Water Quality

Water quality is routinely assessed in many rivers around the state. Based on several water quality parameter,the variables that are regularly monitored include temperature, conductivity, pH, dissolved oxygen, and total suspended solids. Changes in water quality can have a detrimental effect on rivers. Water quality information is to determine the status and water quality in rivers sampling that were normally classified for total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), total dissolved salts (TDS), dissolved organic carbon (DOC) and dissolved oxygen (DO) concentrations, along with pH, turbidity and colour readings (DWER, 2016) .

In Malaysia, river water quality classification and monitoring is quite extensive. There are two primarily methods to classify the river water quality monitoring which is Water Quality Index (WQI) and Standard Interim National Water Quality Standards (INWQS) derived based on the beneficial uses of water (Zainudin, 2010). The INWQS defines six classes (I, IIA, IIB, III, IV and V) which are referred for the classification of rivers based on the descending order of water quality; Class I being the 'best' and Class V being the 'worst'. For Water Quality Index (WQI), six parameters were chosen such as dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), ammoniacal nitrogen (NH_3-N) and pH. Table 2.2 shows the class definition provided in INWQS. While Table 2.3 shows DOE Water Quality Classification Based on WQI.

Table 2.2 : INWQS class definition. (Source: NWQS for Malaysia)

Class	Definition
I	Conservation of natural environment Water supply I—Practically no treatment necessary (except by disinfection or boiling only) Fishery I—Very sensitive aquatic species
IIA	Water supply II—Conventional treatment required Fishery II—Sensitive aquatic species
IIB	Recreational use with body contact Water
III	Water supply III—Extensive treatment required Fishery III—Common of economic value and tolerant species; livestock drinking
IV	Irrigation
V	None of the above

Table 2.3 : DOE water quality classification based on WQI. (Source: NWQS for Malaysia)

Water Quality Index	**INDEX RANGE**		
	Clean	Slightly Polluted	Polluted
Biological Oxygen Demand (BOD)	91-100	80-90	0-79
Ammoniacal Nitrogen (NH_3-N)	92-100	71-91	0-70
Suspended Solids	76-100	70-75	0-69
WQI	81-100	60-80	0-59

2.5.1 Temperature

Water temperature is one of the most important characteristics of an aquatic system as an indicator which can affect the dissolved oxygen levels where the solubility of oxygen decrease as the water temperature increase. Other than that, water temperature can influence the biological process and species composition of the aquatic ecosystem. Water temperature fluctuates and varies along the length of river. Human activities can affecting the change in water temperature which include the discharge of the industrial effluents, urban development, storm water runoff and climate change (RAMP, n.d.) . High temperatures of water will encourages the growth of bacteria and causes depletion in oxygen content of water (Bhatia, 2006).

2.5.2 Dissolved Oxygen

Dissolved Oxygen (DO) is defined as the amount of oxygen that is dissolved in water. It can vary in a daily and seasonal pattern, temperature, salinity and elevation. Oxygen enters the water by absorption from the atmosphere, by rapid movement, or as a waste product of plant photosynthesis. Dissolved oxygen is essential for a healthy aquatic ecosystem. Fish and aquatic animals need the oxygen dissolved in water to survive. The need for oxygen depends on the species and life stage; some organisms are adapted to lower oxygen conditions, while others require higher concentrations. Dissolved oxygen can affect the solubility and availability of nutrients, which can be released from sediments under conditions of low dissolved oxygen (RAMP, n.d.).

Content of dissolved oxygen (DO) in river water is an important factor for determining the need for further bank filtrate treatment before disinfection. If conditions become anaerobic either due to the low DO content in the river water or because of a high oxygen demand due to the presence of microorganisms in the soil, iron and manganese will undergo chemical reduction and solubilize in the water, requiring their removal by further treatment such as aeration and filtration, before disinfection (Jaramillo, 2012).

2.5.3 pH

pH is a measurement of the hydrogen ion (H^+) concentration in water, and is commonly used to describe the acid/base balance of water. The pH of most natural waters is between 6.0 and 8.5. Water pH affects both biological and chemical processes. Values of pH below 4.5 and above 9.5 are usually lethal to aquatic organisms, and even less extreme pH values can affect reproduction and other biological processes. pH affects the solubility of organic compounds, metals, and salts. In highly acidic waters, certain minerals can dissolve and release metals and other chemical substances into the water and can affect reactivity, bioavailability and toxicity (RAMP, n.d.).

2.5.4 Total Dissolved Solids (TDS)

The concentration of total dissolved solids (TDS) is a measurement of the amount of dissolved material in water. TDS includes solutes such as sodium, calcium, magnesium, bicarbonate, chloride and others that remain as solid residue after evaporation of water from the sample. Fresh water usually contain TDS levels between 0 and 1,000 mg/L, depending on the geology of the region, climate and weathering, and other geographical features that affect sources of dissolved material and its transport to a water system (RAMP, n.d.).

2.5.5 Conductivity

Conductivity is a measurement of the ability to conduct an electric current and is the opposite (or reciprocal) of resistance. The higher the concentration of ions in water, the more current the water can conduct. Conductivity is sensitive to the amount of mineral salts in water, and depends on the amount of electrical charge on each ion, ion mobility, and temperature. It is expressed in units of micro Siemens per centimetre (µS/cm), conductivity generally ranges between 10 and 1,000 µS/cm in most rivers or lakes (RAMP, n.d.-b).

2.5.6 Dissolved Organic Carbon (DOC)

Dissolved organic carbon or DOC is a measurement of the amount of organic matter in water that can be passed through a filter, commonly 0.45 µm. For drinking water, dissolved organic carbon is an important water quality parameter measured for several purposes. Elevated levels of DOC may interfere with the effectiveness of disinfection processes such as UV, ozone and chlorination thus should be monitored for removal prior to disinfection (Real Tech, n.d.) .

2.5.7 Total Coliform and *E. coli*

Total Coliform bacteria (TC) are a group of bacteria that are regularly present in environmental waters. Faecal coliforms (FC) and *E. coli* are sub-group of TC that are closely associated with the faeces of people and warm blooded animals. FC or *E. coli* presence can indicate contamination of water supplies resulting in an increased risk of the presence of waterborne pathogens. Bacterial indicators such as TC and *E. coli* are also valuable indicators of the performance of drinking water treatment processes and distribution system integrity (Washington State Department of Health, 2009).

2.5.8 UV_{254}

UV_{254}, also known as the spectral absorption coefficient (SAC), is a water quality test parameter which utilizes light at the UV254 nm wavelength to be able to detect natural organic matter (NOM) in water and wastewater. This is due to the fact that most organic compounds absorb light at the UV254 nm wavelength. Unlike other organic test parameters, UV_{254} has a bias towards reactive or aromatic organic matter which has double bonded ring structures and is typically the most problematic form of organics in water (UV_{254}, 2017) Natural organic matter (NOM) is a precursor of disinfectant by-products (DBPs) that has a wide range of compounds and cannot be directly measured. Instead, the amount of NOM can be expressed by bulk parameters, such as total organic carbon (TOC), dissolved organic carbon (DOC), or UV_{254}, also known as NOM surrogates (Sillanpaa at el., 2015).

2.5.9 Ammoniacal Nitrogen

Ammonical nitrogen in waste waters promotes eutrophication of receiving waters and are potentially toxic to the aquatic life (Gorre, 2015). Ammoniacal nitrogen refers to two chemical compounds which are in equilibrium in water (NH_3, un-ionized and NH^{4+}, ionized). The toxicity of ammonia is primarily attributable to the un-ionized form (NH^3), as opposed to the ionized form (NH^{4+}). In general, more NH_3 and greater toxicity exist at lower pH and temperature (Brian, 2014). Ammoniacal nitrogen acts as an indicator of the pollution from excessive usage of ammonia especially from fertilizers. Ammonia concentration in waters must not exceed the recommended limit as it will harm aquatic life in the river water (Gorre, 2015).

2.5.10 Control Test

Control test is the recovery of the adsorbed material and regeneration of the adsorbent in the treatment (Labastida et al., 2017). The possibility of adsorbent regeneration (desorption) and metal recovery was primarily studied based on the general assumption that regeneration of adsorbent promotes economic adsorption treatment (Isa et al., 2008).

2.6 Summary

Based on the literature review, it can be concluded that the riverbank filtration (RBF) is an efficient treatment and low-cost natural alternative technology to remove surface water contaminants or degraded as infiltrating water moves from the river to pumping wells. However, the effectiveness of RBF system results from a combination of several