# REMOVAL OF TOTAL COLIFORM, E. COLI, $UV_{254}$, PARTICLES, TOTAL DISSOLVED SOLIDS (TDS), SUSPENDED SOLIDS (SS), AND COLOUR USING ZEOLITE AND ACTIVATED CARBON MIXTURE IN RIVERBANK FILTRATION.

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UNIVERSITI SAINS MALAYSIA
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By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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# ABSTRAK

Perbandaran bersama dengan pertumbuhan pesat populasi manusia telah menyebabkan pencemaran air yang ketara. Pada tahun 2006, Jabatan Alam Sekitar (JAS) telah merekodkan sebanyak 18,956 punca-punca tetap yang merangkumi loji rawatan kumbahan (9,060: 47.79% termasuk 601 stesen rangkaian pam), industri pembuatan (8543: 45.07%), ladang ternakan (869: 4.58% ) dan industri berasaskan pertanian (484: 2.55%). Kualiti air sungai dan tasik yang buruk, banjir dan kekurangan air telah menjadi isu utama di Malaysia. Untuk menangani masalah tersebut, Malaysia telah mula menggunakan kaedah penapisan tebing sungai (RBF) untuk abstraksi air. Zeolit dan karbon teraktif diguna sebagai penjerap komposit mempunyai potensi untuk meningkatkan keberkesanan sistem RBF ini. Penyelidikan ini dijalankan untuk meninjau kemungkinan penggunaan kedua-dua bahan tesebut dalam sistem RBF. Ciri-ciri zeolit dan karbon teraktif ditentukan dahulu dengan menggunakan kaedah Imbasan Elektron Microskop (SEM) dan Sinar-X Pembelauan (XRF). Turus penapis direka bentuk menyerupai sistem RBF dan kadar penapisan yang sesuai ditetapkan. Prestasi penapis dalam penyingkiran zarah, jumlah koliform, *E. coli*, pepejal terlarut (TDS), pepejal terenap (SS), $UV_{254}$ dan warna dikaji dengan menggunakan 2 susunan zeolit dan karbon aktif dengan saiz dari 1.18 mm ke 2.0 mm, iaitu 1) media bercampur dan 2) dua lapisan: zeolit (bawah) dan karbon aktif (atas). Berdasarkan keputusan SEM, zeolit yang digunakan terdiri daripada kristal bersaiz mikron dengan liang-liang kecil. Keputusan XRF menunjukkan bahawa zeolit yang digunakan berada dalam kumpulan *Clinoptilolite* dengan komponen utamanya $SiO_2$ (79%) dan $Al_2O_3$ (13%). Bagi karbon aktif pula, keputusan SEM menunjukkan ia adalah sangat amorfus dan strukturnya berlapis-lapis dengan kehadiran rongga-rongga. Keputusan XRF bagi karbon teraktif menunjukkan komponen utamanya adalah C (93%) dan $SiO_2$ (4%), dengan unsur-unsur surih (Fe, Zn dan Cu) sebagai pemangkin. Experimen penapisan pada kadar aliran 18.3 cm$^3$/min dan masa tahanan 30 minit menunjukkan prestasi penyingkiran yang baik terhadap hampir semua parameter kecuali TDS dan zarah. Peratusan penyingkiran jumlah koliform dan *E. coli* adalah sangat baik iaitu masing-masing 95% dan 99%. Seterusnya, 67%-84% kekeruhan berjaya disingkirkan, diikuti warna (45%-70%) dan UV$_{254}$ (20-47%). Zeolit dan karbon teraktif yang beralkali semula jadi menyebabkan peningkatan pH terhadap air yang telah ditapis. Turus A yang terdiri daripada campuran zeolit dan karbon aktif mempunyai prestasi yang lebih baik dalam pengurangan pepejal terampai, warna dan kekeruhan manakala bagi Turus B yang mempunyai dua lapisan, zeolite (bawah) dan karbon aktif (atas) mempunyai prestasi yang lebih baik dalam pengurangan jumlah koliform, *E. coli*, dan UV$_{254}$. Liang-liang zeolit dan karbon aktif diperhati telah diisi oleh bahan pencemar selepas penapisan. Penyingkiran zarah dan jumlah pepejal terlarut (TDS) tidak dapat ditentukan kerana kesan larut resap ke dalam air.

# ABSTRACT

Urbanization together with the exponential growth of human population causes serious water pollution. In 2006, the Department of Environment (DOE) registered 18,956 water pollution point sources comprising mainly sewage treatment plants (9,060 : 47.79% inclusive of 601 Network Pump Stations), manufacturing industries (8,543 : 45.07%), animal farms (869 : 4.58%) and agro-based industries (484 : 2.55%). Poor water quality of rivers and lakes, flooding and water shortage have become major issues in Malaysia. To tackle the problem, Malaysia has started to use river bank filtration (RBF) for water abstraction. Zeolite and activated carbon as composite adsorbent has the potential to enhance the RBF system. Therefore, this study was investigated to look at possibility of using both materials in the RBF system. Both materials were first determined using scanning electron microscopy (SEM) and X-ray fluorescence method. The filter column that resembles RBF system was then designed. The filtration rate that are appropriate for RBF system was pre-determined. The removing performance of particles, total coliform, *E. coli*, total dissolved solids (TDS), suspended solids (SS), $UV_{254}$ and colour was then determined at different configurations as follows: using different arrangements of zeolite and activated carbon with size from 1.18 mm to 2.0 mm, 1) mixed arrangement; 2) and two distinctive layers of zeolite (bottom) and activated carbon (top). The SEM results shown that the zeolite consists of micron-size crystal with small size of pores. Through XRF test, it can be concluded that the zeolite was from clinoptilolite group with main constituents of $SiO_2$ (79%) and $Al_2O_3$ (13%). For activated carbon, SEM results show that it is highly amorphous and has layered-like structures with the presence of cavities. XRF tests for activated carbon shows that its main constituents are C (93%) and $SiO_2$ (4%) with few transition elements (Fe, Zn and Cu) as catalyst within their compounds. Filtration experiments done at flow rate of 18.3 $cm^3$/min and retention time of 30 minutes

have shown good removal performance for almost all the parameters except TDS and particle sizes. Removal of total coliform and *E. coli* were excellent with 95% and 99% removal, respectively. It is then followed by 67% to 84% removal efficiency for turbidity, 45% to 70% for colour and 20% to 47% for $UV_{254}$. Zeolite and activated which are alkaline in nature had caused the increase in pH of water after filtration. Column A which consists of a mixture of zeolite and activated carbon, performed better in removing suspended solids, colour and turbidity whereas for column B which has two distinctive layers of zeolite and activated carbon, performed better in removing total coliform, *E. coli*, and $UV_{254}$. It has been observed that the pollutants filled up the pores of zeolite and activated carbon after filtration. However, concentration of particles and total dissolved solids (TDS) could not be determined due to leaching effect of zeolite and activated carbon into the water.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| COD | Chemical Oxygen Demand |
| DO | Dissolved Oxygen |
| DOC | Dissolved Organic Carbon |
| EBCT | Empty Bed Contact Time |
| HLR | Hydraulic Loading Rate |
| NOM | Natural Organic Matter |
| NWQS | National Water Quality Standards |
| RBF | River Bank Filtration |
| SAC | Special Absorption Coefficient |
| SEM | Scanning Electron Microscopy |
| SMEWW | Standard Methods for the Examination of Water and Wastewater |
| SS | Suspended Solids |
| TDS | Total Dissolved Solids |
| XRF | X-ray Fluorescence |

# NOMENCLATURES

| | |
|---|---|
| $A$ | Cross sectional area |
| $Aeff$ | Effective cross-sectional area |
| $D$ | Diameter |
| $\varepsilon$ | Porosity |
| $h$ | Adsorbent height |
| $Q$ | Flow rate |
| $V$ | Adsorbent volume |
| $V\varepsilon$ | Empty volume |
| $Vw$ | Volume of water |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Malaysia generally receives a rainfall average of 3,000 mm annually which comprises about 97% of raw water supply that comes from the rivers. There are a total of 189 river basins in Malaysia, 89 in the Peninsular Malaysia, 100 in Sabah and Sarawak (WWF, 2008).

Many catchments in developing countries are experiencing rapid urbanization along with the exponential growth of the populations. It is well known that population growth and industrial activities are drivers of water quality change. Due to the high demand of development, the process of deforestation usually removes water basin beneath the forest, resulting in soil erosion and sedimentation. Many researchers found that such deterioration or as well as the root cause of pollution is mainly due to the complex interaction between the engineered infrastructures and social, economic, legal, and political issues during rapid urbanization that causes the livestock farm, heavy metals from factories, mining, and logging activities to pollute the water quality.

The causes of pollution are either point source pollution or non-point source pollution or whether it was caused by human activity or caused by nature. Water pollution in rivers caused by natural factors is closely related to climatic characteristics, geographic and geological conditions as well as rainfall distribution in a particular area as rainfall will affect the water quality. The status or level of pollution on ground water needs to be measured before any actions could be taken to create sustainable rivers and lakes.

Garfi et al. (2016) mentioned that many water treatment plants use a combination of coagulation, sedimentation, filtration and disinfection to provide clean, safe drinking water to the public. In most countries, a combination of coagulation, sedimentation and filtration is the most widely applied water treatment technology and has been used since the early 20th century. In addition, there is other techniques such as chemical precipitation, evaporations and membrane processes are found to be effective in treatment of waste and sewage water (Rajasulochana and Preethy, 2016).

However, riverbank filtration (RBF) has been proven as one of the best water treatment technique for its cost effectiveness and simple skill requirements (Tratchin et al., 2018). Riverbank filtration is a technique that consists of withdrawing water from rivers by pumping wells located in adjacent to the river. The riverbed serves as a natural filter to remove the contaminants that present in the surface water by combining a series of physical, chemical and biological processes (Shrikoti et al., 2016).

The type of media used to treat the water will greatly affect the performance of the riverbank filtration. Activated carbon has been considered as one of the oldest way and widely used adsorbent for water treatment in removing organic and inorganic pollutants. The application of activated carbon in adsorption process is mainly relying on the surface chemistry and pore structure of porous carbons (Bhatnagar et al., 2013). Besides, natural zeolites can also be used as adsorbents of organic and inorganic compounds due to high ion-exchange capacity that serves as molecular filter. Zeolite has been used in many types of industrial applications such as catalysis, environmental remediation and restoration, water purification and removal of heavy metals and radioactive elements (Favvas et al.; Chen et al.; Kragovic et al., cited in De Velasco-Maldonado et al., 2018). Thus, the filtration media can be modified to suit the characteristic of water treatment.

Wahab (2017) used zeolite only as the filter media in his study on RBF. The experiment resulted in the presence of particles which is less than 0.5μm in zeolite after filtration due to straining and ion-exchange process. Removal of particles and TDS could not be determined due to leaching, whereas removal of total coliform and *E. coli* were excellent with almost 100% removal. It is followed by removal of SS, turbidity, colour and $UV_{254}$.

Cheong (2016) utilized zeliac, a composite material consists of zeolite, limestone, activated carbon, rice husk carbon binded with Ordinary Portland Cement (OPC) as filtration media in his RBF. The performance on total coliform and *E. coli* is excellent with removal of almost 100%. Removal of SS, $UV_{254}$ and colour are good. Similarly, the range of particle size and total dissolved solids (TDS) could not be determined due to leaching of zeliac.

Halim et al. (2009) reported that zeolite is hydrophilic with regular aligned molecular level pores and cationic exchange ability, which makes it a good adsorbent for ammonia, metallic ions and catalysts. For activated carbon, it has a hydrophobic surface with pore sizes within nanometer range or above which makes it more suitable for the adsorption of organic substances. A combination of two media can further enhance removal performance in filtration.

## 1.2 Problem Statement

The exploding urban population growth creates unprecedented challenges, among which provision for water and sanitation have been the most pressing and painfully felt when lacking. The rapid population growth leads to increase in demand for clean water, as well as the increase in water pollution due to development. Besides, the impact of the rapid population growth includes the water quality of rivers and lakes, flooding and shortage of water has become one of the major bottlenecks for Malaysia.

RBF can be modified to accommodate the different limitations in order to maximize the effectiveness of the treatment. This objective of this study is to focus on the capability of zeolite and activated carbon as adsorbent to remove total coliform, *E. coli*, $UV_{254}$, particle, total dissolved solids (TDS), suspended solids (SS), and colour in river water through RBF.

## 1.3 Objectives

The objectives in this study are:

1. To determine physical and chemical characteristics of zeolite and activated carbon as adsorbent.
2. To design filter column that resembles riverbank filtration system and to test the filtration rate that are appropriate for riverbank filtration system.
3. To examine removing performance of total coliform, *E. coli*, total dissolved solids (TDS), suspended solids (SS), $UV_{254}$ and colour using difference arrangement of zeolite and activated carbon in filter columns.

## 1.4 Scope of Work

Zeolite and activated carbon characteristics study was first carried out to determine their physical and chemical characteristics by undergoing Scanning Electron Microscopy (SEM) and X-Ray Fluorescence (XRF) method. Next, water characteristics study was carried out to identify the physical characteristics and biological contaminants of water from Sungai Kerian, Lubok Buntar, Perak as a case study site. Column study was set up by using natural zeolite and activated carbon as porous media to adsorb and remove the contaminants in water samples. This column study was conducted for 15 days with flow rate of 18.3 mL/min and retention time of 30 min to mimic kinematic similitude with the pumping well in Lubok Buntar as the velocity of groundwater movement is 1.014 cm/min (measured by colloidal borescope, approximately 1 cm/min). The removal efficiencies were determined by comparing the concentration of the selected parameters before and after the test. Results were then analysed.

## 1.5 Dissertation Outline

The thesis has been categorized into specific chapters for better viewing and understanding of the study. It consists of five chapters namely, introduction, literature review, research design and methodology, research results and discussion, and lastly conclusion and recommendations. Each chapter will discuss different aspect of the study.

**Chapter 1**: Introduction – this chapter gives an overview background of the thesis, followed by the problem statement to identify, and objectives to understand why this research was carried out and its relevance to current times followed by the objectives of this research in order to set the desired target of work.

**Chapter 2**: Literature Review – this chapter discusses the literature review of riverbank filtration including its background, process involved, advantages and disadvantages, limitations, mechanisms in porous media, composite adsorbent of zeolite and activated carbon as well as river water quality related.

**Chapter 3**: Methodology – this chapter highlights the step and procedure involved in conducting the experiment. It includes zeolite and activated carbon preparation, river water sampling, river water characteristics study, column set up, influent and effluent characteristics study.

**Chapter 4**: Results and Discussion – this chapter analyses the results obtained from the experiment conducted. Results are presented in graphical form whereas analysis and discussion are done for explanation.

**Chapter 5**: Conclusion – this chapter concludes the objectives of the research and provide suitable recommendations for improvement in future studies.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview

River bank filtration (RBF) is a cost-effective and natural first-step process of water treatment using water abstraction method which has better abstracted water quality than using a direct abstraction surface water (river water). It has a multiple-barrier to remove many pollutants. In 2013, Malaysia has firstly used RBF in water treatment plants in Jeli, Kelantan, and Kuala Kangsar, Perak (Aziemah et al., 2016).

The main processes in RBF involved in pollution level reduction are dispersion, physical filtration, biodegradation, ion exchange, adsorption, and dilution (Ray et al., 2002). Othman et al. (2015) reported that during the process, the river water passes through riverbed and aquifer sediments that serve as natural filters, and various contaminants such as trace organic pollutants, bacteria, viruses, and inorganic compounds are removed.

The effectiveness of the RBF treatment is generally depending on the physical characteristics of river water and type of filtration media in use.

## 2.2 Riverbank Filtration (RBF)

Umar et al. (2017) reported that historical evolution of riverbank filtration was pioneered by Glasgow Waterworks Company in the United Kingdom around 1810. Surface water has been treated through bank filtration to improve the existing water supply system in countries such as: Switzerland, France, Germany, Finland, Hungary and Netherland.

### 2.2.1 Technique and Process Involved in RBF

As reported by Umar et al. (2017), riverbank filtration (RBF) is a technique in which the bed and bank of a river act as treatment zones for the induced river water. This happens when wells are sufficiently placed adjacent to a river and pumped, the treatment zones will remove most surface water pollutants. The riverbed serves as a natural filter to the induced water and removes the contaminants present in the surface water by concurring physical, chemical, and biological processes.

Umar et al. (2017) also reported that natural attenuation processes such as filtration, sorption, acid-base reaction, oxidation, reduction, hydrolysis and biochemical reactions enable riverbank filtration (RBF) to have high potential to filter contaminants. As surface water infiltrates into the aquifer, follow by production wells, it undergoes riverbank filtration (RBF) which improves the water quality. Site which mostly consists layers of sand and gravel such as river sediments or alluvial aquifer are suitable for riverbank filtration, they can also be located in low permeable zones within the alluvial aquifer such as in silt and clay.

Due to its easy implementation and little maintenance requirements, riverbank filtration is particularly known for the efficient removal of pathogens, suspended solids, toxic algae, or organic trace compounds from surface water, all being water quality parameters of high relevance (Hülshoff et al., 2009).

### 2.2.2 Beneficial Effects of RBF

Riverbank filtration offers freshwater storage in times of heavy precipitation (during monsoon) or elevated stream run-off (snow melt from higher altitudes). Underground freshwater stocks are protected from evaporated and deterioration (Jimenez, cited in Tratschin et al., 2018). They can be stored until dry weather conditions require groundwater abstraction to meet water demand (Hülshoff et al., 2009). This will be increasingly useful and beneficial with the more extreme weather patterns that are being anticipated with climate change and that pose challenges to developing countries, which are usually more vulnerable to water shortage or flooding (Hülshoff et al., 2009).

Riverbank filtration systems can alleviate shock loads resulting from chemical spills or defects in industrial wastewater plants. Moreover, they can equalize temperature differences between surface water and groundwater aquifers; for example, when rivers receive cooling water from a power station (Schmidt et al., 2003).

Tratschin et al. (2018) reported that as it is relatively low cost and the fact that neither high-tech or highly skilled labour is required, riverbank filtration is suitable as a water purification tool in developing countries.

Jaramillo (2012) reported that reduction of pollution levels is proficient through a number of processes such as physical filtration, ion exchange, microbial degradation, precipitation and other factors that also contribute to the treatment are: the river water quality and the groundwater quality, the porosity of the medium, and the water residence time in the aquifer, temperature and pH conditions of water, oxygen concentrations.

The water contaminant removal mechanisms and efficiency in RBF are summarized in Table 2.1.

Table 2.1: Major Finding in RBF (Umar et al., 2017).

| No. | Objectives | Location | Methodology | Major Finding | Reference |
|---|---|---|---|---|---|
| 1 | To determine the suitability of mixed material as artificial barrier in bank filtration | Lubok Buntar, Kedah, Malaysia | Riverbank filtration (RBF), Artificial Barrier (AB) and Soil analysis | Zeolite and granulated activated carbon are suitable and capable to be used as artificial barrier. | Abd Rashid et al., 2015 |
| 2 | To determine water quality improvement during riverbank filtration process | Kota Lama Kiri in Kuala Kangsar, Perak, Malaysia | Riverbank filtration (RBF), Hydrochemical analysis and soil analysis | Up to 98.78% of turbidity was removed while colour and iron were removed to 73.56% and 87.93% respectively. *E. coli* removal was almost 100% for all samples. | Othman et al., 2015 |
| 3 | To determine the effectiveness of riverbank filtration | Jenderam Hilir, Dengkil, Selangor | Resistivity profiling, Hydrochemical analysis, Pumping test and Riverbank filtaration | Turbidity, hardness and TDS were significantly reduced to allowable limits for potable water. 100% removal efficiency was achieved for microorganism | Shamsuddin et al., 2013 |
| 4 | To determine factors affecting contaminant attenuation efficiency during riverbank filtration | Abu Tiega Egypt | Hydrochemical analysis using APHA guidelines | Removal efficiency of algae, bacteria and other suspended matter is very encouraging. Travel time and depth of abstraction wells are the key factors. | Abdalla and Shamrukh, 2011 |
| 5 | To access the efficiency of RBF as an alternative to surface water abstraction for safe drinking water supply | Khabarovsk, Russia | Hydrochemical analysis | RBF provides safe drinking water during periods of accidental spills as wells as the protection against shock loads besides improving drinking water quality. | Kulakov et al, 2011 |
| 6 | To determine water quality improvement after bank filtration | Sidfa RBF Nile River Egypt | Hydrogeochemical analysis | Values of turbidity, chemical species, alkalinity, hardness and TDS were significantly reduced to allowable limits. | Shamrukh and Abdel Wahab, 2008 |

### 2.2.3 Limitations in RBF

Jaramillo (2012) reported that besides the inability to remove certain biological, inorganic and organic contaminants, limitations of RBF associated with the hydrology and dynamics of the river and groundwater cannot be ignored. Changes in hydraulic gradient and hydraulic conductivity produce changes in the pore water velocity as well as in the retention time, which may limit or change the biogeochemistry activity that occurs in the hyporheic zone. Changes in water temperature could weaken the final quality of filtered water.

Jaramillo (2012) also reported that efficiency and performance of RBF can also be compromised by scouring processes occurred on the river bed and banks when the flow rates are very high, which is a usual problem.

Another limitation associated with RBF is the obstruction or clogging of the porous media. There are four types of clogging: mechanical, physical, biological and chemical.

Jaramillo reported that mechanical clogging is defined as the blocking of flow through porous media due to the entrapment of gas. Physical clogging is caused by the continual percolation of river water containing suspended matter due to well pumping. Biological clogging is created by excessive biomass accumulation in the riverbed, whereas chemical clogging is resulted by the precipitation of compounds into the pores of the aquifer.

Jaramillo (2012) reported that clogging may be limited or removed by the self-cleaning potential of the river, scouring. Scouring process is the result of the shear forces imparted by the movement of water flowing into the river, and the resistance to the movement provided by the riverbed itself, which is a function of the river slope, the vertical velocity profile and sediment transport.

### 2.2.4 Treatment Processes of RBF

Jaramillo (2012) reported that several attenuation processes that are involved for the improvement of water quality include hydrodynamic, mechanical, biological and physicochemical. Diagram of processes affecting water quality in RBF is shown in Figure 2.1.

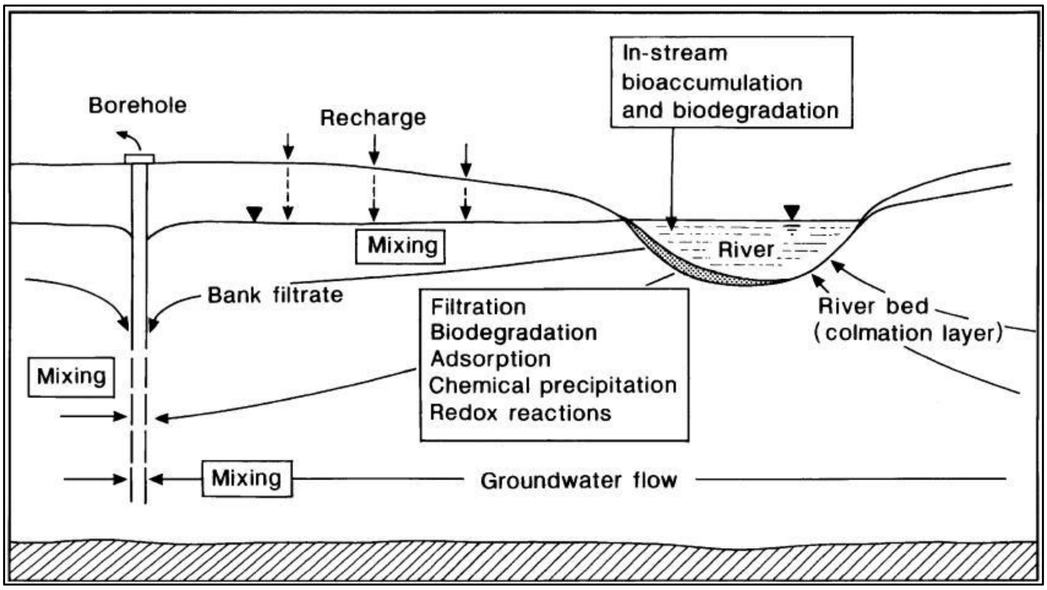

Figure 2.1: Processes affecting the water quality in RBF
(Hiscock and Grischek, 2002).

Jaramillo (2012) reported that hydrodynamic processes consist of convective-dispersive transport and dilution. The aquifer serves as a filter for temporal variation of pollutants compounds in river prompted by spills. High frequency changes in the surface water quality are reduced in groundwater, dilution takes place when river water mixes with groundwater, which is usually of higher quality, further enhancing the quality of bank filtrate.

Jaramillo (2012) reported that mechanical processes are the most vital as it involves natural filtration of fine sediments, particulate organic matter and pathogens, especially in the first few meters from the river to well. Through straining and filtration RBF retains suspended matter in soil, depending on pore throat size (Hülshoff et al., 2009).

Biodegradation is the major driver for redox processes occurring during subsurface passage and is responsible for the breakdown of dissolved and sediment-bound organic matter (Hülshoff et al., 2009). Biological contaminants are reduced by a series of processes including adsorption to aquifer materials and inactivation (Schmidt et al., 2003). Tratschin (2018) reported that when groundwater velocity is slow and when the aquifer consists of granular materials with high grain surface contact, the removal of biological contaminants through RBF is the most.

Jaramillo (2012) also reported that physicochemical processes associate with sorption, precipitation reactions, flocculation, coagulation and redox. All these processes control the removal of particles, directly affect the chemical evolution of water by affecting the concentration and behaviour of metals and other inorganic compounds.

## 2.3 Mechanisms in Porous Media

Gutierrez et al. (2017) mentioned that riverbank filtration removes contaminants through a series of processes namely, filtration, sorption of pollutants to soil particles, microbial degradation, chemical precipitation, ion exchange, and oxidation/reduction. In the first centimeters of the riverbed a fine sediments' layer is formed, also known as cake layer, called schmutzdecke if a highly active biological layer is involved. A certain degree of clogging is desired since it can be favourable for water quality improvement due to the extension of travelling times, particulate removal and the richness of processes occurring in the schmutzdecke.

Guetierrez et al. (2017) also mentioned that the schmutzdecke and upper layers are responsible for most of the elimination of volatile organic carbon and is extremely efficient in eliminating viruses. There is an occurrence of 50% total dissolved organic matter removal in the first few centimeters of the infiltration surface due to the biological activity in the developed biomass. Removal of organic matter, pathogens and chemicals happens in the schmutzdecke through predation, scavenging and metabolic breakdown mechanisms.

## 2.4 Composite of Zeolite and Activated Carbon

The filtration media to be used is consisted of the mixture of activated carbon (AC) and zeolite. Activated Carbon and zeolites have their own advantages and disadvantages. So, a blend of the two can combine the shortcomings of either of them (Eapen et al., 2016).

Halim et al. (2010) reported that zeolite is hydrophilic with regular aligned molecular level pores and cationic exchange ability, which makes it a good adsorbent for ammonia, metallic ions and catalysts. For activated carbon, it has a hydrophobic surface with pore sizes within nanometer range or above which makes it more ideal for the adsorption of organic substances.

Apart from improving adsorption capacities, the combination of zeolite and activated carbon as natural ion exchanger are capable of enhancing the adsorbing performance in both inorganic (especially ammonia) and organic compounds due to its role in chemical group present on its surface (Halim et al., 2010).

### 2.4.1 Zeolite

Zeolites are hydrated aluminosilicate solid minerals with many different crystalline structures which are built from the elements aluminium, oxygen, silicon and alkaline-Earth metals with water molecules trapped in the gaps between them (Okada et al., 2005). Valuable physicochemical properties of zeolites such as cation exchange, molecular sieving, catalysis and sorption made them widely used as adsorbents in separation and purification processes (Wang and Peng, 2010).

Foo and Hameed (2011) reported that zeolite is specified as a diverse group of inorganic, alkaline and hydrated crystalline aluminium-silicates, tetrahedral connecting neighbouring corners by sharing their oxygen atoms. Potential of zeolite is exclusively featured by the high reactivity for complete elimination of stubborn pollutants and environmental remediation, mainly hinges on its synergetic adsorption strength, controllable pore structure, excellent chemical stability and superior ability in removing a wide range of organic and inorganic pollutants dissolved in aqueous media.

Tabatabaei et al. (2012) reported that the framework of zeolite contains various channels and cavities where cations and water molecules are located. The channel structure of zeolites acts as a molecular sieve for selective cation exchange. The selectivity of different ions is determined by several factors such as the size and state of salvation of the ions, the charge (Si to Al ratio) and geometry of the framework, number of cation sites available for occupation inside the framework and temperature.

Natural zeolites have shown varying ion-exchange capacity for cations such as ammonium and heavy metal ions, adsorption of anions and organics from solution (Wang and Peng, 2010). Tabatabaei et al. (2012) reported that ion exchange of a specific cation is strongly affected by the presence of competitive cations and complexion reagents such as anions. De Velasco-Maldonado et al. (2018) reported that natural zeolites are used as adsorbents of organic and inorganic compounds due to the high ion-exchange capacity and shape-selective structure that acts as molecular sieve.

Study done by Halim et al., 2010 demonstrates that both chemical adsorption (dominant) and physical adsorption played a role in the adsorption of organic constituents on zeolite. Chemical adsorption relates to ion exchange activity on adsorbent surface whereas physical adsorption refers to physical attachment of non-polar adsorbate on very large surface area because of the existence of macropore, mesopore and micropore. High cation exchange capacity along with moderate surface area in zeolite allow the combination of chemical and physical adsorption.

### 2.4.2 Activated Carbon

Eapen et al. (2016) reported that activated carbon (AC) is famous for its highly developed porosity, large surface area, variable characteristics of surface chemistry and high degree of surface reactivity. Treatment of wastewater and contaminated groundwater by using AC is increasing worldwide as a result of limited source of water supply.

Hung et al. (2005) reported that activated carbon is used in water treatment to remove organic compounds that cause objectionable taste, odour, and colour. In advanced wastewater treatment, carbon is used to adsorb organic compounds, and in industrial wastewater treatment, it is used to adsorb toxic organic compounds.

Activated carbon has a large number of capillaries within the carbon particles. The total surface available for adsorption of solute includes the surfaces of the pores as well as the external surface of particles. In fact, the pore surface area is much larger than the external surface area of particles and most of the adsorption occurs on the pores' surfaces. The ratio of total surface area to mass of activated carbon is very high (Hung et al., 2005)

Bjatnagar et al. (2013) reported that the high surface area, large porosity, well developed internal pore structure of activated carbon consists of micro-, meso- and macropores as well as a wide spectrum of functional groups present on the surface of activated carbon make it a versatile material especially in environmental field.

All activated carbon serves on a principle called adsorption, which is an adherence of a substance to the surface of the activated carbon. The adsorption process results from interactions between the carbon surface and the adsorbate can be electrostatic or non-electrostatic (Eapen et al., 2016). Physical adsorption is mainly due to van der Waal's forces and is a reversible process (Hung et al., 2015).

The attraction of a substance in a solution (adsorbate) to an activated carbon particle (adsorbent) occurs in three define steps (Hung et al., 2006):

1. The adsorbed molecule must be transferred from the bulk phase of the solution to the surface of the adsorbent particle. In doing so, it must pass through a film of solvent that surrounds the adsorbent particle, this is termed film diffusion.
2. The adsorbate molecule must be transferred to an adsorption site on the inside of the pore. This process is called pore diffusion.
3. The adsorbate must become attached to the surface of the adsorbent. This is the actual adsorption step.

Halim et al. (2010) reported that general activated carbon does not have enough adsorption capacity for ammonia as it usually possesses a non-polar surface due to high temperature manufacturing condition, which is a downside because of poor interaction with some polar adsorbates. Zeolite is extensively applied as a natural ion exchanger to remove ammonia and other inorganic pollutants from wastewater.

Apart from improving adsorption capacities, the combination of zeolite and activated carbon as natural ion exchanger are capable of enhancing adsorbing performance in both inorganic (especially ammonia) and organic compounds due to its role in chemical group present on its surface (Halim et al., 2010).

## 2.5 River Water Quality

The Department of Environment (DOE) has been monitoring river mainly to establish baselines and to detect water quality changes as well as to identify pollution sources. Water quality data were utilised to regulate the water quality status whether in clean, slightly polluted or polluted category in order to classify the rivers to Class I, II, III, IV or V based on Interim National Water Quality Standards for Malaysia (INWQS). It is computed based on 6 main parameters (Department of Environment, 2018):

1. Dissolved Oxygen (DO)
2. Suspended Solids (SS)
3. Ammoniacal Nitrogen ($NH_3$-N)
4. Biochemical Oxygen Demand (BOD)
5. Chemical Oxygen Demand (COD)
6. pH

Water classes and uses are shown in Table 2.2.

Table 2.2: Water classes and uses (Department of Environment, 2016).

| Class | Uses |
|---|---|
| Class I | Conservation of natural environment.<br>Water Supply I- Practically no treatment necessary.<br>Fishery I- Very sensitive aquatic species. |
| Class IIA | Water Supply II- Conventional treatment required.<br>Fishery II- Sensitive aquatic species. |
| Class IIB | Recreational use with body contact. |
| Class III | Water Supply II- Extensive treatment required.<br>Fishery III- Common, of economic value and tolerant species; livestock drinking |
| Class IV | Irrigation |
| Class V | None of the above |

In this study, certain parameters of river water are investigated including total colifrom, *E. coli*, $UV_{254}$, solids (particles, TDS, SS), true colour, temperature, pH, dissolved oxygen (DO), conductivity, turbidity, dissolved organic carbon (DOC), ammoniacal nitrogen ($NH_3$-N) and chemical oxygen demand (COD).

### 2.5.1 Total Coliform

The presence of pathogens is determined with indirect evidence by testing for an ‘indicator’ organism such as coliform bacteria. Total coliforms consist of bacteria that are found in soil, in water that has been influenced by surface water, and in human or animal waste. Coliforms come from the same sources as pathogenic organisms. Coliforms are relatively easy to identify, usually present in large numbers and respond to the environment and wastewater treatment similarly to many pathogens. Therefore, testing for coliform bacteria can be a logical indication of whether other pathogenic bacteria are present (New York State Department of Health, 2011).

### 2.5.2 Eschrichia coli

Escherichia coli, *E. coli* is a type of fecal coliform bacteria commonly found in the intestines of animals and humans. The presence of *E. coli* in water is a strong indication of recent sewage or animal waste contamination. Sewage may contain many types of disease-causing organisms. *E. coli* may be washed into rivers, lakes or groundwater during rainfalls or snow melts. Although most strains of *E. coli* are harmless, *E. coli* 0157:H7 produces a powerful toxin and can cause severe illness (Apec Water, 2018).

### 2.5.3 $UV_{254}$

$UV_{254}$ is a measurement of the absorbance of light by a water sample at 254nm wavelength (Processinstrument, 2017), also known as the Spectral Absorption Coefficient (SAC) (Real Tech Water). Light at the 254nm wavelength is of particular interest since it is a wavelength that is very readily absorbed by organic matter in the water (Processinstrument, 2017). Different from other organic test parameters, $UV_{254}$ has a bias towards reactive or aromatic organic matter. Natural organic matter (NOM) is a vital parameter for measuring water quality. Levels of NOM are linked with taste, odour, chemical treatment dosage and disinfectant by-product (DBP) formation (Grierson, 2016). $UV_{254}$ is typically represented as a calculation of UV absorbance (UVA) or UV transmittance (UVT) (Real Tech Water, 2017).

### 2.5.4 Solids (particle, TDS, SS)

Total suspended solid (TSS) are particles that are larger than 2 microns found in water column. Most suspended solids are made up of inorganic materials, though bacteria and algae can also contribute to the solids concentration (Kentucky Water Watch, cited in Fondriest, 2018) and organic particles from decomposing materials (Murphy, cited in Fondriest, 2018). High levels of total suspended solids will increase water temperatures and decrease dissolved oxygen (DO) (EPA, cited in Fondriest, 2018). Reason behind is suspended particles absorb more heat from solar radiation than water molecules will (Michigan Department of Environmental Quality, cited in Fondriest, 2018). Furthermore, the increased surface temperature can cause stratification or layering of a body of water (Kentucky Water Watch, cited in Fondriest, 2018).

Water typically contains very finely divided solid particles, ranging in size from colloidal dimensions to about 100um, composed of inorganic and organic materials that are derived from soils and rocks (Drinking Water and Health: Vol.1, 1977). Sediment often used to indicate soil-based, mineral matter (clay, silt and sand), decomposing organic substances and inorganic biogenic material. Most mineral sediment comes from erosion and weathering while organic sediment is typically detritus and decomposing material such as algae (EPA, cited in Fondriest, 2018).

Total dissolved solids (TDS) combine the sum of all ion particles that are smaller than 2 microns (EPA, cited in Fondriest, 2018). This includes all the disassociated electrolytes that contribute to salinity concentrations, as well as other compounds such as dissolved organic matter. TDS can include organic solutes (such as hydrocarbons and urea) in addition to the salt ions in wastewater or polluted areas (Thompson, cited in

Fondriest, 2018). Dissolved solids are important to aquatic life by keeping cell density balanced (EPA, cited in Fondriest, 2018).

### 2.5.5 True Colour

True colour of water is considered to be the only parameter that attributable to substances in solution after the suspended material has been removed. Apparent colour is used for colour that includes the effect from suspended material. The unit of colour considered as a standard is the colour produced by the platinum cobalt method of measurement where one unit of colour equals one milligram per litre of platinum in water. Colour can be caused by minerals and organic compounds (Synder, 2011).

### 2.5.6 Temperature

Water temperature affects the metabolic rates and biological activity of aquatic organisms and can inhibit plant respiration and photosynthesis too (Wetzel, cited in Fondriest, 2018). Factor that causes temperature change includes sunlight (UW-Green Bay, cited in Fondriest, 2018), atmosphere (The Concord Consortium, cited in Fondriest, 2018), turbidity (EPA, cited in Fondriest, 2018), confluence (The Concord Consortium, cited in Fondriest, 2018), and man-made influences. Dissolved oxygen concentrations are dependent on temperature. The solubility of oxygen and other gases will decrease as temperature increases (Perlman, cited in Fondriest, 2018). Water temperature can affect conductivity in two ways, ionic mobility through viscosity and ionic concentration. An increase in temperature will decrease viscosity, thus increases the mobility of ions and conductivity (Miller et al., cited in Fondriest, 2018). As warm water can dissolve several minerals and salts more easily than cold water, the ionic concentration is often higher (Perlman, cited in Fondriest, 2018).

### 2.5.7 pH

pH is a figure between 0 and 14 defining how acidic or basic a body of water is along a logarithmic scale (Merriam-Webster, cited in Fondriest, 2016). The lower the number, the more acidic the water is. The higher the number, the more basic it is. pH stands for ‘power of hydrogen’. The numerical value of pH is determined by the molar concentration of hydrogen ions (H+) (Nave, cited in Fondriest, 2016). The higher the $H^+$ concentration, the lower the pH, and the higher the OH- concentration, the higher the pH. pH affects the solubility and toxicity of chemicals and heavy metals in water (USGS, cited in Fondriest, 2016), with majority of aquatic creatures prefer a pH range of 6.5-9.0 (EPA, cited in Fondriest, 2016).

### 2.5.8 Dissolved Oxygen (DO)

Dissolved oxygen is the level of free, non-compound oxygen present in water or other liquids. It is a vital parameter because of its influence on the organisms living within a body of water (Washington State Department of Ecology, cited in Fondriest, 2016). Dissolved oxygen enters water through air or as plant byproduct. Amount of oxygen needed varies from organisms to organisms. Microbes such as bacteria also require dissolved oxygen, to decompose organic material at the bottom of water. Microbial decomposition is important to nutrient recycling (Katznelson, cited in Fondriest, 2016).

### 2.5.9 Conductivity

Conductivity is a measure of water capability to pass electrical flow. This ability is directly related to concentration of ions in water (EPA, cited in Fondriest, 2016). These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides and carbonate compounds (Miller et al., cited in Fondriest, 2016). The more ions that are present, the higher the conductivity of water. A sudden increase or decrease in conductivity in a body of water can indicate pollution. Agricultural runoff or a sewage leak will increase conductivity due to the additional chloride, phosphate and nitrate ions (EPA, cited in Fondriest, 2016). An oil spill or addition of other organic compound would decrease conductivity as these elements do not break down into ions (LCRA, cited in Fondriest, 2016).

### 2.5.10 Turbidity

Turbidity is an optical determination of water clarity (EPA, cited in Fondriest, 2018), based on the amount of light scattered by particles in the water column (Perlman, cited in Fondriest, 2016). Turbid water will appear cloudy, murky or otherwise colored. Turbidity measurements are often used as an indicator of water quality based on clarity and estimated total suspended solids in water (Perlman, cited in Fondriest, 2016). Turbidity can come from suspended sediment, inorganic materials, organic matter, colored dissolved organic matter, fluorescent dissolved organic matter and other dyes (Anderson, cited in Fondriest, 2016).