Faculty of Engineering

THE INFLUENCE OF FILTER MEDIA CONFIGURATION ON THE QUALITY OF TREATED WATER

Atiqah Baiduri binti Mustajab

Bachelor of Chemical Engineering with Honours

2022

THE INFLUENCE OF FILTER MEDIA CONFIGURATION ON THE QUALITY OF TREATED WATER

ATIQAH BAIDURI BINTI MUSTAJAB

A dissertation submitted in partial fulfillment
of the requirement for the degree of

Bachelor of Chemical Engineering with Honours

Faculty of Engineering

Universiti Malaysia Sarawak

2022

Dedicated to my beloved parents, family, and close friends, who always bestow me sustainable motivation and encouragement

ACKNOWLEDGEMENT

I would like to take this opportunity to thank my biggest advocate without whom this would not have been possible; Allah. All praises to Allah that I am blessed with the opportunity to pursue my study and chase my dreams. I would also like to express immense gratitude to my parents, my siblings, and my friends for their support. They are my main source of strength and I would not be as determined as I am now without them. I would like to sincerely thank my supervisor, Mr. Mohd Farid bin Atan for his guidance, motivation, and encouragement to finish this research project. It has been a great pleasure and honor to have him as my supervisor. All in all, this research project has pushed me to test my limits. This thesis is a testament to the fact that none of us would accomplish anything without the amazing people in our lives.

ABSTRACT

Providing clean and safe water has become a staggering challenge due to the increasing demand for clean water supply. In this research project, a multimedia filtration system with silica sand, activated carbon, and zeolite as the filter media will be used to treat the water sample, which is rainwater mixed with clay soil. From the study, the results indicated that configuration 2 with a higher total mass of 800 g which consists of 5% Zeolite, 5% Activated Carbon, 70% Silica sand of 2.3 mm, and 20% Silica sand of 0.6 mm produce the best results for all water parameters. This is because the increase in the total mass of filter media will also increase the efficiency of the filtration process as it increases the surface area of the filter media in contact with the particles of contaminant. Meanwhile, concerning the configurations of the same total mass of 400 g, configuration 5 gives the highest reduction of contaminants. This is due to the higher portion of Zeolite and Activated Carbon compared to other configurations of the same mass. Configuration 5 consists of 20% of Activated Carbon and Zeolite, while configurations 1,3, and 4 consists of 5%, 10%, and 15% of Activated Carbon respectively. Hence, a higher proportion of filter media with high adsorption capacity are more effective compared to other configurations considering the low filtration rates. Moreover, it is found that filtration at the lowest flow rate could achieve the maximum removal of polluting contaminants. Hence, three important aspects must be considered for the implementation of the multimedia filtration system which includes the configuration of filter media, the total mass of filter media, and the filtration flow rate. A new design of a multimedia filtration system and some recommendations are proposed to overcome the limitations of the filtration system used in this study.

Keywords: Multimedia filtration, filter media, configuration.

ABSTRAK

Menyediakan air bersih dan selamat telah menjadi satu cabaran berikutan peningkatan permintaan terhadap bekalan air bersih. Dalam projek penyelidikan ini, sistem penapisan multimedia dengan pasir silika, karbon teraktif dan zeolit sebagai media penapis akan digunakan untuk merawat sampel air iaitu air hujan bercampur dengan tanah liat. Daripada kajian, keputusan menunjukkan bahawa konfigurasi 2 dengan jumlah jisim yang lebih tinggi iaitu 800 g yang terdiri daripada 5% Zeolit, 5% Karbon Teraktif, 70% Pasir Silika 2.3 mm, dan 20% Pasir Silika 0.6 mm menghasilkan hasil yang terbaik. untuk semua parameter air. Ini kerana peningkatan jumlah jisim media penapis juga akan meningkatkan kecekapan proses penapisan kerana ia meningkatkan luas permukaan media penapis yang bersentuhan dengan zarah bahan cemar. Sementara itu, mengenai konfigurasi jumlah jisim yang sama iaitu 400 g, konfigurasi 5 memberikan pengurangan bahan cemar yang paling tinggi. Ini disebabkan oleh bahagian Zeolit dan Karbon Teraktif yang lebih tinggi berbanding dengan konfigurasi lain yang mempunyai jisim yang sama. Konfigurasi 5 terdiri daripada 20% Karbon Teraktif dan Zeolit, manakala konfigurasi 1,3, dan 4 masing-masing terdiri daripada 5%, 10%, dan 15% Karbon Teraktif. Oleh itu, bahagian media penapis yang lebih tinggi dengan kapasiti penjerapan yang tinggi adalah lebih berkesan berbanding dengan konfigurasi lain memandangkan kadar penapisan yang rendah. Selain itu, didapati bahawa penapisan pada kadar aliran terendah boleh mencapai penyingkiran maksimum bahan cemar yang mencemarkan. Oleh itu, tiga aspek penting mesti dipertimbangkan untuk pelaksanaan sistem penapisan multimedia yang merangkumi konfigurasi media penapis, jumlah jisim media penapis, dan kadar aliran penapisan. Reka bentuk baharu sistem penapisan multimedia dan beberapa cadangan dicadangkan untuk mengatasi batasan sistem penapisan yang digunakan dalam kajian ini.

Kata kunci: Penapisan multimedia, media penapis, konfigurasi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Activated carbon
AAS	Atomic Absorption Spectrophotometry
ACF	Activated carbon fibre
BOD	Biochemical oxygen demand
CFU	Colony Forming Unit
COD	Chemical oxygen demand
DOE	Department of Environment
GAC	Granular activated carbon
GGA	Glucose-glutamic acid
JBALB	Jabatan Bekalan Air Luar Bandard
KWB	Kuching Water Board
PAC	Powdered activated carbon
NTU	Nephelometric Turbidity Units
NWQS	National Water Quality Standards
RLU	Relative Light Units
RWH	Rainwater harvesting
SAWAS	Sarawak Alternative Water Supply
SS	Suspended solids
SWB	Sibu Water Board
TSS	Total Suspended Solids
UNIMAS	Universiti Malaysia Sarawal
WQI	Water quality index

CHAPTER 1

INTRODUCTION

1.1 Background

Due to the tremendous development and the rapid growth of the population in recent decades, safe and clean treated water supply has become a major concern in many parts of the world (Al-Mamun & Zainudin, 2013). According to Chung (2015), the increasing amount of home and industrial waste contributes to the degradation of river water quality, which is the primary cause of water disruption in communities. The increased urbanization has resulted in a significant rise in demand for treated water across the nation (Garba et al., 2021). Water utilities have been undergoing a significant paradigm shift in the way they manage water supply and monitor water quality. The approach includes the way the water utilities manage the water treatment process as well as the water quality control procedures from the raw water sources to the water distributed to the public (Shakeran, 2004).

Recently, a growing number of research on improving the water quality of raw water sources have been conducted by prominent scholars in the field to meet the increasing demand. Most of the regions in the country are not facing any serious shortage of water supply due to the high annual rainfall, except in some of the dry regions and the rural areas of the Peninsula, Sabah, and Sarawak (Hafizi et al, 2018). Supplying treated water to rural areas has become a huge challenge because the majority of the potable water in Malaysia is tapped from the rivers (Shaheed and Mohtar, 2015). Karunakaran et al. (2021) eloquently stated that the percentage of piped water in rural areas of Sabah and Sarawak is still relatively low compared with the rural areas of Peninsular Malaysia with only 62% of the areas equipped with piped water in 2020. The lower coverage of piped water in the rural areas of Sabah and Sarawak is mainly due to the high cost of providing the infrastructure (Ayob & Rahmat, 2017). This is because of the undulating topography in those areas (Mahyan & Selaman, 2016). Furthermore, the rural population in the two states is scattered over vast rural areas which causes some areas to become less noticeable

(Khalid, 2018). It is also uneconomical to install water pipes to reach the scattered rural areas (Ling et al., 2017).

This research project consists of several stages which are literature review analysis, water samples preparation, laboratory testing, determining the effective filter media configuration, and providing some suggestions and recommendations to implement the filter media configuration in real case conditions. An in-depth literature review analysis is conducted in Semester 1 and followed by laboratory testing and analysis in Semester 2 of the 2021/2022 academic session. The water sample was prepared by mixing 10 g of clay soil with 1000 g of rainwater, assuming 1kg of water is equivalent to 1000 mL. The water used is rainwater because rainwater harvesting is a widely-used alternative for supplementing the public water supply in the rural areas of Sarawak (Mahyan and Selaman, 2016). After that, the chemical, physical, and biological characteristics of the water samples prepared before and after the filtration process were analyzed in terms of the pH, turbidity, Total Suspended Solid (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), as well as the total Iron (Fe) concentration in the water. The experimental data obtained will be used to determine the effective filter media configuration to treat the contaminated water so that it complies with the raw water standard by the Ministry of Health Malaysia.

The water filtration system used in this research project is the multi-media filtration system which is operated in batch mode. There are 4 filter media used in this research project which include silica sand of 0.6mm, 1.2mm, and 2.3mm, activated carbon, and zeolite. To evaluate the performance of the selected filter media configuration, all the mentioned water parameters of the treated water are determined to ensure that the treated water adhered to the raw water standards regulated by the Ministry of Health Malaysia. Firstly, the configuration applied in the filtration system is the one being used in SMK Ulu Balingian which consists of Zeolite (5%), Activated Carbon (5%), Silica sand of 2.3 mm (70%), and Silica sand of 0.6 mm (20%) with a total mass of 400 g. Secondly, the total mass of filter media will be increased to 800 g with the same ratio and proportion for each filter media as the previous configuration to see the effect of mass on the effectiveness of the filtration process. For the third, fourth, and fifth configurations, the proportion of Zeolite, Activated Carbon, and Silica Sand of 2.3 mm are varied while the proportion of Silica Sand of 0.6 mm is kept constant as it serves as the base or the final filter medium in the filtration system. The influence of the filter media configuration concerning each water parameter will be analyzed. Finally, the effective configuration of filter media in terms of mass will be expressed in percentage for ease of implementation for future works.

1.2 Problem Statement

Providing clean and safe water has become a staggering challenge due to the increasing demand for clean water supply. Despite that, there are no serious issues of water disruption to communities in most of the regions in Malaysia due to the high annual rainfall across the country, but the problem arises in some regions with lower coverage of piped water, especially in the rural areas of the Peninsula, Sabah, and Sarawak (Hafizi et al, 2018). Supported by Karunakaran et al. (2021), the percentage of piped water in rural areas of Sabah and Sarawak is still low as only 62% of the areas are equipped with piped water in 2020. Therefore, a growing number of studies on the water treatment process especially on the filtration system have been conducted to improve the treated water quality in those areas. Nevertheless, the researchers only acknowledged the types and components of filter media used, but their studies lack actual findings and do not mention the specific configuration of filter media used in water treatment plants in rural areas in Malaysia that successfully implemented the filtration process. As a result, there is a scarcity of quantitative and qualitative data on the use of effective filter media in Malaysian water treatment plants. In addition, the studies that provide justifiable information on the configuration of the multimedia filtration system for rural areas applications are still sparse. As a result, there is a research gap in this field. To fill this research gap, the goal of this research project is to conduct preliminary studies on the impact of filter media configuration on treated water quality. The effective filter media configuration will be determined as a contribution to future research toward developing an efficient water filtration system to resolve water supply issues faced by people in rural areas.

1.3 Research Questions

This research project will be focusing on the study of the influence of filter media configuration on the quality of treated water and below are the research questions.

i. How will different filter media configurations influence the quality of treated water?

ii. Which filter media configuration is the most effective and feasible for treating the contaminated water?
iii. What are the correlations between parameters involved in the water filtration process?

1.4 Aim and Objectives of Study

The overall aim of this research project is to study the influence of the filter media configuration on the quality of treated water. Specifically, this research project focuses on the pretreatment of contaminated water by using different configurations of filter media which include silica sand, activated carbon (AC), and zeolite. Thus, this aim can be achieved by the successful fulfillment of the following objectives:

i. To evaluate the chemical, physical, and biological characteristics of the water samples.
ii. To identify the effective filter media configuration to treat the contaminated water.
iii. To analyze the correlation between the parameters involved during the water filtration process.

1.5 Scopes of Study

The scope of this research project covers the study of the chemical, physical, and biological characteristics of the water samples to identify the effective filter media configuration to treat the contaminated water. The filter media selected in this research project are silica sand, activated carbon, and zeolite. Firstly, the project is started by identifying the potential commercial filter media used in the existing literature review by prominent scholars and researchers in this area. This is crucial so that the background and the implementation of the filter media are well understood to have a deeper understanding of the concept of filter media configuration. Next, the effective filter media configuration used to treat the contaminated water will be determined and presented in the form of a percentage. Therefore, samples will be prepared by mixing 10 g and 1000 mL of rainwater. The water samples are prepared to imitate the real condition of raw water in rural areas of Sarawak. In this research project, the water quality parameters that will be tested for the water samples prepared include the pH, turbidity, total suspended solids (TSS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD), as well as total Iron (Fe) content. The water quality parameters will be tested before and after the water samples undergo the treatment process by using a simple multi-media filtration system occupied with a fixed configuration of filter media which include silica sand, activated carbon (AC), and zeolite. Finally, the effective configuration to treat the contaminated water will be identified from the experimental data obtained and some suggestions and recommendations will be listed by the end of this research project to improve the effectiveness of the filter media configuration implementation. All in all, the scope of research covers all the objectives mentioned in **Section 1.4**. The in-depth literature review is conducted to discuss the concept of filter media, followed by creating the water samples to imitate the real condition of raw water in rural areas of Sarawak. Next, the water quality parameters will be analyzed, and lastly, the effective filter media configuration will be identified and the recommendations for improvements will be listed.

1.6 Significance of Study

This remarkable research project can bring the attention of many researchers in this area to the implementation of the effective configuration of filter media, and eventually place the attractiveness of the effective configuration into the industry's spotlight. The research project also can help the rural communities to find solutions to their water disruption problem and provide the solution for treating the water to meet the increasing demand. This filter media configuration can be applied in the construction of water treatment plants in the affected regions.

1.7 Summary

In this chapter, the general overview of this research project is discussed in detail. The background, the problem statement, the research questions, objectives, scopes of the study as well as its significance are presented in this chapter. Overall, this chapter is important to give a brief idea of the research project and provide a solid foundation as a guideline to proceed with the next chapters.

Chapter 2

LITERATURE REVIEW

2.1 Overview

This chapter reviews the raw water sources in Sarawak and the challenges in providing clean and safe treated water supply to the community. Secondly, this chapter includes a review of the water filtration systems typically used in the water industry as well as the types of filter media applied in the research project. The justification for the filter media selected from the existing journals and articles is also provided. Moreover, an in-depth literature review is also conducted on the water parameters used to determine the quality of the treated water. Finally, the raw water standards by the Ministry of Health Malaysia that are used as a guideline in this research project will be included as well.

2.2 Raw Water Sources in Sarawak

Access to safe drinking water is a basic human right as it is fundamental to health. According to Annua et al. (2020), 663 million people across the globe still drink from underdeveloped water sources such as poorly maintained groundwater and surface water. Although Malaysia is a tropical country that receives high rainfall over the year, the country nevertheless has water shortages and water quality problems. The rising urbanization and the population increment in Sarawak have created concerns about whether the current water supply will be sufficient to meet future demand. This section emphasizes the identification of the potential raw water sources in Sarawak. Besides, the quality of the raw water sources in the rural areas of Sarawak from existing articles and journals will be reviewed to provide a guideline in the selection of the water parameters that need to be considered in this research project. It is important to understand the availability of the raw water source to address the potential alternatives and probable challenges for future water supply improvements. According to Mahyan and Selaman

(2016), the typical raw water sources in rural areas of Sarawak are surface water, groundwater, and rainwater. Shakeran (2004) stated that the water authorities that are responsible for the water resource management in Sarawak are Kuching Water Board (KWB), Sibu Water Board (SWB), LAKU Management Sdn. Bhd., and Sarawak Rural Water Supply Department (JBALB). Although the most commonly used water source in Sarawak is surface water, other raw water sources such as groundwater and river water are also widely used in Sarawak, especially in rural areas. This is supported by the Sarawak Alternative Water Supply (SAWAS), which is a Sarawak government effort run by the Sarawak Rural Water Supply Department (JBALB) under the Ministry of Utilities Sarawak. SAWAS is one of the strategies for realizing Sarawak's goal of 100 percent water supply coverage in the rural areas by 2025. The alternative raw water supply includes rainwater, gravity feed water, and groundwater. **Figure 2.1** shows the water supply alternatives in different locations throughout Sarawak.

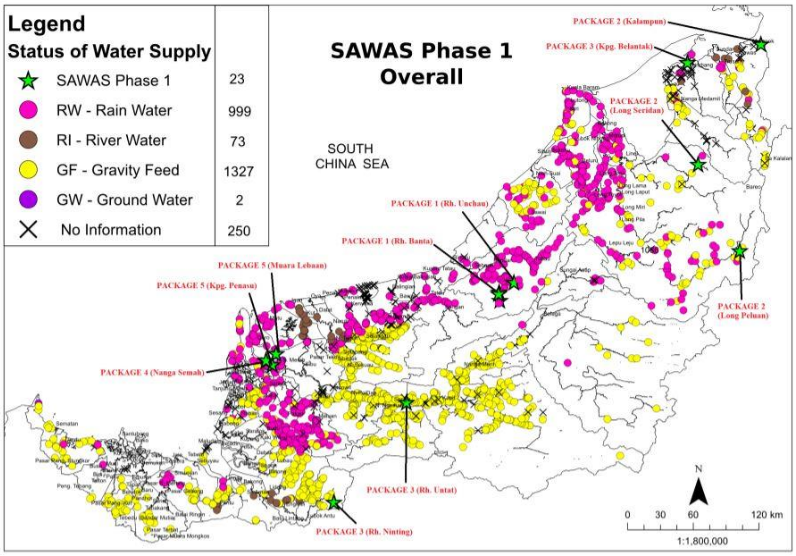

Figure 2.1 Water supply alternatives in rural areas of Sarawak (JBALB, 2021)

As depicted in the figure, the water supply in the rural areas of Sarawak is mainly derived from river water, groundwater, rainwater, and gravity-fed water. The gravity-fed water supply system in Sarawak is typically derived from a small upland river or stream which relies on the force of gravity to help the water flow to the rural residential areas (Shakeran, 2004). Muloiwa et al. (2017) stated that this system is widely used in rural areas because the water is usually from the impounded raw water source within a protected catchment which requires minimum or no treatment. Since the gravity-fed water supply is derived from the upland rivers and streams, the raw water source for the system is typically the surface water. Therefore, in this chapter, there are three (3) main raw water sources that will be discussed, which are surface water, groundwater, and rainwater.

2.2.1 Surface Water

Surface water is the main raw water source in Sarawak (Mahyan and Selaman, 2016). Khublaryan (2009) mentioned that surface water includes rivers, streams, and lakes. River water in Sarawak is important for the state's socio-economic development because a huge area of the state is dominated by river systems, which play an important role as the state's life-sustaining water source (Ling et al., 2017). Zakaria (2000, as cited in Shakeran, 2004) stated that more than 97% of the rivers in Malaysia are utilized for producing a clean and safe water supply for the public. This is supported by Goi (2020) who eloquently mentioned that 98% of the water used for industrial and domestic purposes is from the rivers whereby 70% of the water resources are used for agricultural activities. Furthermore, Shakeran (2004) also mentioned that there are 91 water treatment plants in Sarawak are using river water as the raw water source. For instance, the Sarawak River has become the main raw water source that supplies approximately 98% of the total water distributed to the capital of the state, Kuching City, and the surrounding areas (Kuok et al., 2011).

Since the Sarawak River are also essential for tourism and agricultural development, the water resources are constantly depleted. Van Vliet et al. (2021) mentioned that water scarcity is resulting from both water quantity and water quality problems. Therefore, proper water resource management and water quality monitoring are crucial to ensure the raw water supply is safe for public use and sufficient to meet the increasing demand. There are two primary methods employed by the Department of Environment (DOE) to evaluate the river water quality in Malaysia, which are the Water Quality Index (WQI) and the National Water Quality Standards (NWQS) (Huang et al., 2015; Zainudin, 2010). Al-Mamun and Zainudin (2013) mentioned that there are 5 (I, II, III, IV, and V) classifications of the water quality index (WQI). The description for each classification is shown in **Table 2.1** below.

Table 2.1 Water Classes and Description (Al-Mamun and Zainudin, 2013)

Class	Description
I	There is no need for a treatment facility because the water is of excellent quality.
IIA	The water is of good quality, and currently, most of the raw water supply used is under this category. It is possible to use a standard water treatment system to treat the water.
IIB	The evaluation for water under this category is based on the characteristics of the water for recreational purposes.
III	Extensive treatment is required so that the water under this category can be used by the public.
IV	This classification determines the water quality needed for irrigation in agricultural processes.
V	This category includes the water that is not used for the above purposes.

Goi (2020) in his study presented the data on river quality in 2016 and 2017 as shown in **Figure 2.2**. As depicted in **Figure 2.2**, the quality of most of the rivers in Malaysia is classified under Water Quality Index Class II (Clean) and Class III (Slightly polluted).

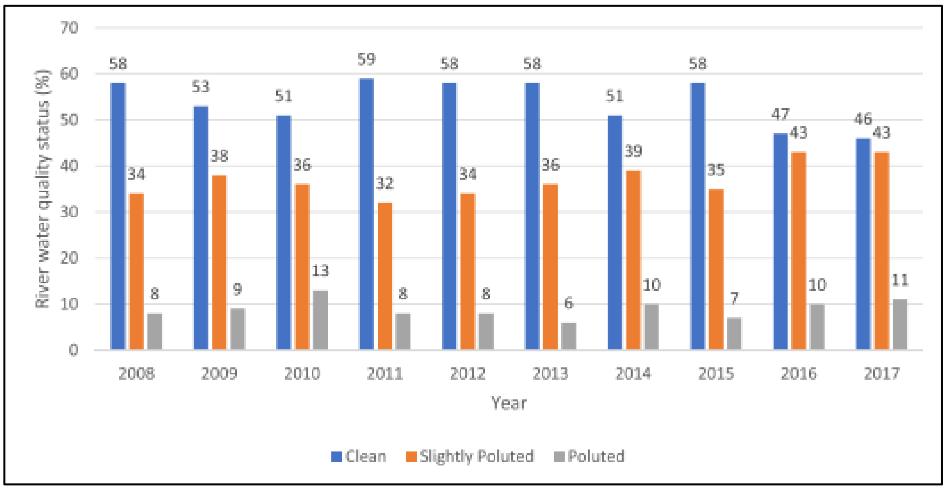

Figure 2.2 The river water quality in Malaysia from 2008 to 2017 (Goi, 2020)

In Malaysia, 53% of the river's water quality was categorized as polluted and slightly polluted (Goi, 2020). There are two types of water contamination sources, namely the point sources and non-point sources (Wu and Chen, 2013). According to Huang et al. (2015), point sources of pollution have a fixed discharge point whereas non-point sources do not have a fixed discharge point. Ling et al. (2017) mentioned that the increase in the levels of pollution of river waters is mainly caused by the point sources which include the discharge from industrial, agricultural, and animal husbandry activities. Besides, Goi (2020) also presented data on the quality of the rivers in each state in Malaysia as shown in **Figure 2.3**. As can be observed from **Figure 2.3**, the number of rivers that are categorized as slightly polluted is higher than the clean rivers in Sarawak. Therefore, all water authorities, the agencies involved and the local communities should work together to improve the river water quality as the river is the essential raw water supply for the public.

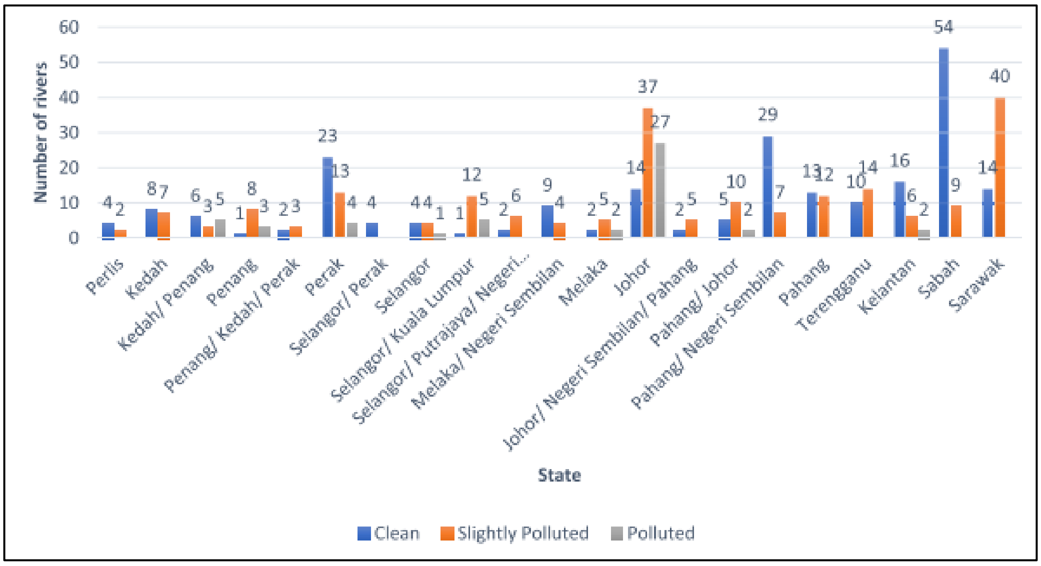

Figure 2.3 River water quality by each state from 2008 to 2017 (Goi, 2020)

Besides the river, the other surface water used for water supply in Sarawak is the lake water. Huang et al. (2015) stated that there are 4 main lakes in Sarawak, namely Batang Ai, Sika, Loagan Bunut, and Tasik Biru. All the lakes in Sarawak are used for different purposes. However, only Sika Lake in Bintulu serves as a raw water source (Huang et al. 2015). The status of the lakes is shown in **Table 2.2** below.

Table 2.2 The status of lakes in Sarawak (Huang et al., 2015)

Name	Uses
Batang Ai	Hydroelectric power generation
Sika	Water supply
Loagan Bunut	Sarawak's largest natural lake and a spot for tourism.
Tasik Biru	Ex-mining pool

2.2.2 Groundwater

Groundwater is typically used as an alternative raw water source as it usually requires lower cost and has less exposure to pollution sources because the water exists below the ground and is tapped into the land surface from wells (Mahyan and Selaman, 2016). Ayob and Rahmat (2017) stated that groundwater is considered a renewable water resource, however, the recharging rate is very slow. This is because the availability of groundwater hugely depends on physiography, climate, and the rate of water consumption (Madhnure & Jain, 2006). For instance, 18,184 m^3 of water being supplied to a steel manufacturing plant originated from the aquifer due to the Langat River scarcity in Selangor (Ayob and Rahmat, 2017). There are, however, some significant drawbacks that have thus far limited the use of groundwater as an alternative water resource which need to be emphasized. As the groundwater is being over-exploited and approximately only 6% of the water is replenished in 5 decades, the groundwater levels have declined and the water quality is also negatively affected (Chung, 2015). Hence, it is important to recharge the depleted aquifers immediately to prevent the issues from worsening.

The groundwater model, pumping test, and flow model are three techniques that can be used to determine groundwater levels (Segal, 2004). On the other hand, the aquifers which are a body of saturated porous rock or sediment containing groundwater can be recharged for potable uses by two main techniques, namely surface spreading and direct injection (Ayob and Rahmat, 2017). These two techniques are different in terms of the water collection method and the treatment process involved. Aquifer recharge by using the spreading surface technique is performed whereby the water from the reclamation plant will undergo filtration through the soil layers before the water ultimately becomes