THE PERFORMANCE OF INTEGRATED GROUNDWATER TREATMENT SYSTEM IN TREATING SHALLOW GROUNDWATER IN PARIT RAJA, JOHOR

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To my beloved father, mother, sisters and husband. Thank you for all your supports and always being there for me. Without all of you, I could not have achieved successful life and become a better person

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ABSTRACT

Groundwater can be an alternative source to meet the demand for clean water supply. Unfortunately, lots of contaminant present in groundwater have made it unsafe for domestic use and drinking. Therefore, groundwater should be treated to an acceptable level before consumption. The overall aim of this study is to improve groundwater quality using Integrated Groundwater Treatment System (IGTs). The system was designed and installed in the hydro-meteorology station at UTHM. Initially, hydrochemical characterisation of the groundwater were determined using piper diagram and statistical analysis. The optimum conditions for each treatment system were identified prior to the installation of IGTs. The system consists of several treatments namely pre-aeration, post-aeration, sedimentation, filtration with customised filter tank and ceramic filter, and dilution with harvested rainwater. From the results obtained, major cation and anion found were Na and Cl, respectively. The type of water that predominates the study area is Na–Cl which indicates that the groundwater is influenced by seawater intrusion. For post-aeration and sedimentation processes, the most suitable time taken ranged between 18 hours and 48 hours. For filtration, the most suitable customised filter tank was Filter type D with brick layer as the dominant component. Meanwhile, ceramic filter was selected to be used in the candle filter. Using IGTs, the system was able to reduce concentrations of TDS, Na, Cl, Fe, and Mn by 70.3%, 23.42%, 81.81%, 90.48%, and 61.62%, respectively. Due to very high concentrations of parameters in the study area, not all parameters met the Drinking Water Quality Standard and Recommended Raw Water Quality Standard by Ministry of Health Malaysia. Overall, the study results could serve as important baseline information for authorities in Malaysia to plan and manage groundwater in the future.

ABSTRAK

Air bawah tanah boleh menjadi sumber alternatif untuk memenuhi permintaan bekalan air bersih. Malangnya, banyak bahan pencemar yang terdapat di dalam air bawah tanah menjadikannya tidak selamat untuk kegunaan domestik dan diminum. Oleh sebab itu, air bawah tanah harus dirawat ke tahap yang boleh diterima sebelum digunakan. Tujuan kajian ini adalah untuk meningkatkan kualiti air bawah tanah menggunakan Sistem Rawatan Air Tanah Bersepadu. Sistem ini telah direka dan dipasang di stesen hidro-meteorologi di UTHM.Untuk permulaan, pencirian hidrokimia air bawah tanah telah ditentukan dengan menggunakan gambarajah piper dan analisis statistik. Keadaan optimum untuk setiap sistem rawatan telah dikenal pasti sebelum pemasangan sistem tersebut. Sistem ini terdiri daripada beberapa rawatan iaitu pra-pengudaraan, pasca-pengudaraan, pemendapan, penapisan dengan tangki penapis dan penapis seramik, serta proses pencairan dengan air hujan yang dituai. Dari hasil yang diperoleh, kation dan anion utama yang dijumpai masing-masing adalah Na dan Cl. Jenis air yang mendominasi kawasan kajian adalah Na–Cl yang menunjukkan bahawa air bawah tanah dipengaruhi oleh air laut. Untuk proses pasca pengudaraan dan pemendapan, masa yang paling sesuai diambil adalah diantara 18 jam dan 48 jam. Untuk proses penapisan pula, tangki penapis yang paling sesuai ialah tangki jenis D iaitu dengan lapisan bata sebagai komponen yang mendominasi. Sementara itu, penapis seramik dipilih untuk digunakan di dalam penapis lilin. Dengan menggunakan sistem ini, kepekatan TDS, Na, Cl, Fe, dan Mn dapat dikurangkan masing-masing sebanyak 70.3%, 23.42%, 81.81%, 90.48%, dan 61.62% penyingkiran. Disebabkan oleh kepekatan parameter yang sangat tinggi di kawasan kajian, tidak semua parameter dapat memenuhi Standard Kualiti Air Minum dan Standard Kualiti Air Mentah yang Disyorkan oleh Kementerian Kesihatan Malaysia. Secara keseluruhannya, hasil kajian ini boleh menjadi maklumat asas penting bagi pihak berkuasa di Malaysia untuk merancang dan menguruskan air bawah tanah pada masa akan datang.

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LIST OF ABBREVIATIONS

As	-	Arsenic
Ca	-	Calcium
Cl	-	Chloride
Cu	-	Cupper
EC	-	Electric conductivity
Fe	-	Ferum
HCO_3	-	Bicarbonate
ICP-MS	-	Coupled Plasma-Mass Spectrometry
IEA	-	International Energy Agency
K	-	Potassium
Km	-	Kilometer
Mg	-	Magnessium
Mg/l	-	Millgram per liter
Mn	-	Manganase
MOH	-	Ministry of Health
Na	-	Sodium
PET	-	Polyethylene teraphthalate
ppb	-	part per billion
SO_4	-	Sulfate
SS	-	Suspended solid
TDS	-	Total Dissolve Solid
UTHM	-	University Tun Hussein Malaysia
VOCs	-	Volatile Organic Chemicals
WHO	-	World Health Organisation
Zn	-	Zinc

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Malaysia has abundant water resources and receives 3000 mm annual rainfall with reported total production of daily water supply of 16,536 million liters in 2017 (Kei, 2017). Despite the abundant quantities of surface water available, water shortages have occurred frequently in Malaysia due to increasing demand, improper water resources, lack of river basin management, and growing population. Municipal development, industrialisation, and irrigation of agriculture as well as climate change have increased the growing demand and pressure on Malaysian water resources thereby enhancing water pollution (Afroz & Masud, 2014). In addition to pollution issues, water supply especially from dams at certain places is not sufficient for daily use especially during dry period.

Non-potable water applications used for flushing toilets, doing laundry, washing cars, and watering plants contribute to high consumption of water. To overcome these problems, alternative water supply from other resources such as groundwater can be used as a substitute for treated water. Thus, treated water can be saved and used for other purposes. At the same time, it could reduce water bills and operating costs of water treatment plants. Groundwater is obtained by digging wells and natural springs. The constituents of groundwater are controlled by environmental and anthropogenic factors such as precipitation, interaction between groundwater and aquifer, geological settings, weathering of parent rock, and human activities (Li, Qian & Wu, 2014; Hamzah *et al.*, 2017). Groundwater quality problems are usually associated with the high hardness, high salinity, and elevation of other contaminants such as ionic compounds and heavy metals that can harm human health (Nouri *et al.*, 2006; Samsudin *et al.*, 2008; Li *et al.*, 2014). Contaminated groundwater cannot be used for domestic purposes as it can lead to serious health threats to humans. Thus, contaminated groundwater needs to be treated properly before use.

Many treatments and technologies have been developed to improve the quality of groundwater. Most of the treatments involve physical, chemical, and biological processes such as membrane separation, chemical precipitation, coagulation, flocculation, reverse osmosis, and biosorption (Rajapakse & Fenner 2011; Akbar *et al.*, 2015; Kasim, Mohammad & Abdullah, 2016). However, there are a few major drawbacks to these methods such as toxic sludge generation, handling and disposal problems, high cost, technical constraints, and incomplete pollutant removal. Therefore, the main aim of this study is to improve shallow groundwater quality using an integrated treatment system consisting of several treatments namely aeration, sedimentation, filtration, and dilution.

1.2 Problem statement

Rapid pace of urbanisation, industrialisation, population growth, and economic growth have led to an increased demand of treated water. According to David (2010), household water demand accounts for 50% of all water consumptions that includes bathing, washing clothes, flushing toilets, and watering lawns and gardens. In order to reduce the usage of treated water for non-potable use, alternative water sources such as groundwater are seen as a potential and can be further explored.

The clay type soil in study area has made the soil unable to retain much water deep into the ground. However, water can still be extracted from shallow groundwater. Shallow groundwater is much easier to exploit, but it is vulnerable to pollutants such as heavy metals and its quality is easily influenced by natural water-rock interactions and anthropogenic activities (Li *et al.*, 2013). Groundwater in this study area is influenced by seawater from ancient water intrusion. The water samples contain high mineral content such as inorganic salts and organic matter. Thus, shallow groundwater in this study required some treatments before it can be used.

Several studies and techniques have been conducted and discovered to improve the quality of groundwater ranging from physical, chemical, physiochemical, and biological treatments (Lim *et al.*, 2014; Bai *et al.*, 2016). Each of these methods has been proven to improve the quality of groundwater. However, the efficiency of each treatment method is limited to the removal of certain parameters. Thus, multiple water treatment methods are necessary as one treatment method may be insufficient to improve the groundwater quality for a specific requirement. Due to these reasons, many studies have shown potential in combining the treatment methods to improve the groundwater quality (Daud *et al.*, 2013; Musa *et al.*, 2015a; Daud *et al.*, 2016; Kadir, 2016). Therefore, this study intends to develop an integrated groundwater treatments system that combines multiple treatments and techniques to treat the pollutants.

1.3 Objectives

The aim of this study is to improve the groundwater quality based on computed water quality index values. The objectives are as follows:

1. To determine the hydrochemical characteristics of groundwater.
2. To optimise the conditions of single treatment in removing selected parameters from groundwater.
3. To investigate the efficiency and performance of Integrated Groundwater Treatment System (IGTs) in improving groundwater quality.

1.4 Scope of work

The objectives of the study were achieved by undertaking the following tasks:

1. Groundwater samples were collected at 15 m from a 20 m depth existing tube well.

2. All parameters selected were analysed by following the Standard Method for Examination of Water and Waste Water (APHA, 2017).
3. The optimum conditions of a single treatment (i.e. aeration, sedimentation, and filtration) in removing selected parameters were identified individually.
4. The experiment for dilution was carried out and tested at the laboratory.
5. IGTs consisted of several treatments namely aeration, sedimentation, filtration, and dilution with rainwater.
6. The current study only focused on water quality.
7. The results obtained were compared with Recommended Raw Water Quality and Drinking Water Quality Standard (MOH, 2004).

1.5 Outline of the thesis

This thesis consists of five chapters. Chapter 1 describes the general perspective of groundwater as an alternative water resource, issues related to groundwater quality, common treatments used in improving groundwater quality, and significance of the study. It also includes the background, problem statement, objectives, scope, and outline of the thesis.

Chapter 2 reviews different topics related to the research. This chapter provides a comprehensive review related to issues on water usage and demand, groundwater as an alternative water resource, characteristics of groundwater quality, and potential water treatment techniques. Major references are critically reviewed to give a clear view on the expectations from the current effort.

Chapter 3 describes the methodology of this research. The research approaches, process, and design to achieve the aim of this study are discussed in detail in three sections in this chapter. First section describes the study area, procedures in determining the groundwater characteristics that consist of sampling and laboratory procedures, and groundwater classification analysis procedure. Second stage discusses the optimisation of a single treatment process in determining optimum conditions in removing selected parameters from groundwater. Finally, the third section explains the design and concept of IGTs in improving groundwater quality.

Chapter 4 highlights the results of the study in accordance with the objectives. The results of this study are compared to standard and previous research. These include the characteristics of groundwater in study area, the effects of each single treatment and its optimum conditions in removing pollutants, and also the performance of IGTs in improving water quality.

Chapter 5 presents the summary and main conclusions drawn from the research. The fulfilment of the objectives is supported with results and analyses from Chapter 4. Recommendations for future work are also presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses in detail the issues related to groundwater as an alternative water resource. The potential of groundwater and its characteristics are also presented. Some findings reported from other studies are critically reviewed in terms of water quality treatment techniques.

2.2 Water usage and demand

Today, water availability is a growing global concern. According to WHO (2019), in 2017, 785 million people around the world had no basic drinking water services at home while 144 million people relied on untreated water sources from surface water such as lakes and streams. An average of 842,000 people die from water related illnesses each year (WHO, 2014). If current water usage increases, by 2025, half of the world's population will live in water scarcity (WHO, 2019). According to IEA (2012), water consumption will increase by 80% while 20% of water withdrawal will increase for energy production by 2035. Rapid pace of urbanisation, industrialisation, population growth, and economic growth have led to an increase in food expenditure, which requires a large amount of treated water (Kei, 2017). In addition, climate change has led to an increase in drought, and thus global warming. As surrounding temperature increases, more water is required for irrigation, livestock, and crops.

As a result of population growth, rapid industrialisation, development, as well as pollution and climate change, the demand for water consumption in Malaysia is expanding (Kei, 2017). Malaysia's water demand per capita per day increases about 7.6 litres per year (Sung, 2011). These demands include potable and non-potable water consumption. Ominously, the increase in water consumption does not correspond with the quantity of water resources in this country. In fact, Malaysia's water reserves per capita per day has been declining at a rate of 5.8 L per year since 2005 (Lani, Yusof & Syafiuddin, 2018). At this rate, Malaysia will be left with almost no water reserves by 2025. This will lead to competition for water among consumers.

According to Ayob (2018), 50% of the total water used comes from non-potable water consumption which includes bathing, washing clothes, flushing toilets, and watering lawns and gardens. Alternative water is often treated to non-potable standards which is not safe for human consumption (Hardy, *et al*., 2015). Common uses of alternative water include groundwater extraction, rainwater harvesting, grey water, and reclaimed wastewater (Islam *et al*., 2016). Groundwater extraction and rainwater harvesting are the most common sources especially in residential areas, institutions, and commercial centers. Towards achieving the developed nation status in the 21st century, government has supported water conservation by promoting water management such as Integrated Water Resources Management (IWRM) and monitoring programme for groundwater (Ahmed, Siwar & Begum, 2014).

2.3 Groundwater potential as water resource

Sources of water could be found everywhere and perceived within every reachable environment as it is within the oceans, streams, lakes, rivers, and underground. The total amount of water on Earth is estimated at approximately 1.4×10^9 km^3 (Masaru, 2011; Srivastava & Ashu, 2017). Table 2.1 lists the dispersion of water distribution around the world.

It is observed that 97.2% of Earth's water is in the oceans, which is saline water and cannot be consumed. Only 2.8% is fresh water and the largest fresh water is from glacier. However, groundwater and surface water are the two most used reservoirs by humans due to their accessibility factor. Although fresh surface water is used more frequently due to ease of accessibility, groundwater is approximately 100 times more abundant than fresh surface water.

Table 2.1: Percentage of water distribution (Fitts, 2012).

No.	Types of reservoir	Percentages (%)
1	Ocean	97.2%
2	Ice Caps / Glaciers	2.14%
3	Groundwater to depth of 13,000 ft.	0.61%
4	Fresh Water Lakes	0.009%
5	Inland Seas/ Salt Lakes	0.008%
6	Soil and Subsoil Moisture	0.005%
7	Atmosphere	0.001%
8	Rivers	0.0001%
9	Biota (within living plants, animals, and humans)	0.0001%

According to Freeze and Cherry (2000), groundwater is the water found underground in the cracks and spaces of soil, sand, and rock. It is stored in geological formations of soil, sand, and rocks called aquifers and moves slowly through them. It comes from natural precipitation process of rain and from melting process of snow and ice and is the source of water for aquifers, springs, and wells. Almost 30% of the world population depends on groundwater for their daily activities including cooking, bathing, and cleaning (Fitts, 2012).

Groundwater has been widely used around the world. Several countries such as China, Saudi Arabia, Iceland, Mongolia, India, and Libya depend on groundwater as 75% of their fresh water supply (Stiefel & Melesse, 2009; Li *et al.*, 2013; Kumar, Elango & James, 2014). Almost one third of the world population has been estimated to rely on groundwater for their everyday consumption (Masaru, 2011). Every year, about 900 km^3 of groundwater has been pumped up from groundwater sources for human activities such as agriculture, industrial development, and recreational activities (Van *et al.*, 2009; Adeleye *et al.*, 2015).

Groundwater development in Malaysia has started since the early 1900s in Kelantan (Suratman, 2004; Kasim *et al.*, 2016). To date, about 65% of the groundwater exploited is for domestic supply, 35% for industrial supply, and 5% for agricultural use. About 0.2 million m^3/d of groundwater is being exploited in

Peninsular Malaysia (Ismail, 2009; Shamsuddin *et al.*, 2018). In Peninsular Malaysia, potential groundwater resources may be divided into four main categories according to the types of aquifers and their hydrogeological properties (Yunus, 2009; Praveena *et al.*, 2011). The most productive aquifer is the alluvium, composed of sand and gravel that can yield from 50 to 100 m^3/h/well. Certain parts of rural areas in the country still depend on groundwater from wells and shallow tube wells to meet their daily needs (Daud *et al.*, 2016). In Kelantan, nearly 70% of the population uses groundwater for public and domestic supplies. In Terengganu, groundwater usage is limited to supplementary domestic use in small islands, agricultural farms, and some educational campuses (Hamzah *et al.*, 2017)

The government has amended the Seventh Malaysia Plan to give the highest priority to groundwater development and environmental conservation. The Minerals and Geoscience Division of the Ministry of Natural Resources and Environment had initiated the preparation of the Strategic Plan for the Management of Groundwater Resources and was accepted by National Water Resources Council in August 2008 (Abd Razak & Abd Karim, 2009; Ayob, 2018). In the same year, the Minerals and Geoscience Department Malaysia had prepared the action plans for the country's groundwater development (Yunus, 2009).

In industrial sector, local factories have already started to change their water source from treated water to groundwater. The largest extraction of groundwater for industrial use in Malaysia is at the Megasteel or Amsteel factory at Brooklands Estate in Kuala Langat District. Sapari, Azie & Jusoh (2011) found that many factories in Melaka, Negeri Sembilan, Selangor, and Kedah that employ groundwater are located in areas underlain by metasedimentary rock. According to Hamzah *et al.* (2017), groundwater located in areas underlain by metasedimentary rock can produce huge amount of water because it can retain much water. However, it is alleged to have very low porosity and low permeability.

2.3.1 Characteristics of groundwater

Groundwater has the potential to meet the growing water demand as it is an easily accessible and widely available conjunctive source of water. It has been used for drinking, irrigation, and various industrial purposes all over the world especially in

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