DEVELOPMENT OF GROUNDWATER QUALITY INDEX FOR NON-POTABLE USE VIA PROPORTIONAL TECHNIQUE

By

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Faculty : Forestry and Environment

Groundwater resources have also been used for many years in other countries such as India, Saudi Arabia, the United Kingdom, and the Netherlands. Furthermore, groundwater resources have long been used in several states in Malaysia, for example in Kelantan, Kedah, and Terengganu and several parts in remote areas that have difficulty getting the tap water supply and nearby the coastal areas such as Sabah and Sarawak. The development of the groundwater quality index (GWQI) in this study is vital as the groundwater is considered an alternative water source for non-potable use. The inadequacy of Malaysia's groundwater quality standard highlighted the importance of the GWQI's development in determining groundwater quality. The aim of this study was to develop a GWQI that represents the water quality data as a single number to present the quality of groundwater. This study was focusing the groundwater sources in the agricultural areas because it is believed that many wells were excavated for irrigation purposes in agricultural areas. The groundwater samples were collected from 13 groundwater wells in the Northern and Southern Kuala Langat regions from February 2018 to January 2019. A total of 34 parameters have been identified for the development of the GWQI such as salinity, pH, nitrate, BOD, COD, major ions, and trace elements. Statistical analysis was conducted to identify the dominant parameters in the GWQI. From the Principal Component Analysis (PCA), seven parameters have been identified as dominant parameters, which were magnesium, calcium, potassium, sodium, chloride, electrical conductivity, and chemical oxygen demand which were suitable to determine the quality of groundwater. This study found that the GWQI in Kuala Langat, Selangor shows a value of 64 which is classified as good quality. This GWQI has also been verified by measuring the quality of groundwater in Kota Bharu, Kelantan, which has similar features to the current study in terms of agricultural activity and proximity to coastal areas. Therefore, the GWQI shows an excellent index value of 96 which the groundwater in Kota Bharu, Kelantan is very clean and suitable for use as non-potable water utilization. GWQI has also been tested for sensitivity analysis to determine its reliability and suitability to be

used and assess the quality of groundwater in other areas. This study contributes to new knowledge by determining the quality of groundwater for non-potable use, filling a gap in the study for groundwater exploitation. Furthermore, unlike the GWQI introduced by DOE Malaysia, which included parameters such as pH, iron, dissolved solids, nitrate, sulfate, phenol, and E. coli, this index does not include parameters needed for drinking purposes. However, the parameter from major ions, electrical conductivity, and COD was disclosed to the GWQI in this study to estimate the quality of groundwater for non-potable usage. As a result, the findings of this study are innovative, as a suitable GWQI has been created to determine groundwater quality, particularly for non-potable applications. This GWQI is beneficial to the community, practitioners, researchers, policymakers, industrial sectors, and government agencies. Furthermore, this index can help to detect any form of pollution and the pollution can be reduced by controlling the source of pollutants. As a recommendation for future studies, this GWQI requires a detailed health assessment and considered the important parameters for drinking water supply as recommended by the Ministry of Health whether it is safe for human health.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN INDEKS KUALITI AIR BAWAH TANAH BAGI KEGUNAAN BUKAN UNTUK TUJUAN MINUMAN MELALUI TEKNIK PERKADARAN

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Sumber air bawah tanah juga telah digunakan selama bertahun-tahun di negara lain seperti India, Arab Saudi, United Kingdom, dan Belanda. Tambahan pula, sumber air bawah tanah telah lama digunakan di beberapa negeri di Malaysia, contohnya di Kelantan, Kedah, dan Terengganu dan beberapa bahagian di kawasan terpencil yang mengalami kesukaran mendapatkan bekalan air paip dan berdekatan dengan kawasan pantai seperti Sabah dan Sarawak. Pembangunan indeks kualiti air bawah tanah (IKABT) dalam kajian ini adalah penting kerana air bawah tanah dianggap sebagai sumber air alternatif untuk kegunaan tidak boleh diminum. Kekurangan standard kualiti air bawah tanah Malaysia menunjukkan kepentingan pembangunan IKABT dalam menentukan kualiti air bawah tanah. Matlamat kajian ini adalah untuk membangunkan IKABT yang mewakili data kualiti air sebagai satu nombor untuk mempersembahkan kualiti air bawah tanah. Kajian ini memfokuskan sumber air bawah tanah di kawasan pertanian kerana dipercayai banyak telaga digali untuk tujuan pengairan di kawasan pertanian. Sampel air bawah tanah telah diambil dari 13 telaga air bawah tanah di Utara dan Selatan Kuala Langat dari Februari 2018 hingga Januari 2019. Sebanyak 34 parameter telah dikenal pasti untuk pembangunan IKABT seperti kemasinan, pH, nitrat, BOD, COD, ion utama, dan unsur surih. Analisis statistik telah dijalankan untuk mengenal pasti parameter dominan dalam IKABT. Daripada Analisis Komponen Utama (PCA), tujuh parameter telah dikenal pasti sebagai parameter dominan, iaitu magnesium, kalsium, kalium, natrium, klorida, kekonduksian elektrik, dan permintaan oksigen kimia yang sesuai untuk menentukan kualiti air bawah tanah. Kajian ini mendapati IKABT di Kuala Langat, Selangor menunjukkan nilai 64 yang diklasifikasikan sebagai kualiti yang baik. IKABT ini juga telah disahkan dengan mengukur kualiti air bawah tanah di Kota Bharu, Kelantan yang mempunyai ciri-ciri yang hampir sama dengan kajian semasa dari segi aktiviti pertanian dan berdekatan dengan kawasan pantai. Oleh itu, IKABT menunjukkan nilai indeks yang sangat baik iaitu 96 yang mana air bawah tanah di Kota Bharu, Kelantan adalah sangat bersih dan sesuai digunakan sebagai penggunaan air tidak boleh

diminum. IKABT juga telah diuji untuk analisis sensitiviti untuk menentukan kebolehpercayaan dan kesesuaiannya untuk digunakan dan menilai kualiti air bawah tanah di kawasan lain. Kajian ini menyumbang kepada pengetahuan baru dengan menentukan kualiti air bawah tanah untuk kegunaan tidak boleh diminum, mengisi jurang dalam kajian untuk eksploitasi air bawah tanah. Tambahan pula, tidak seperti IKABT yang diperkenalkan oleh JAS Malaysia, yang merangkumi parameter seperti pH, besi, pepejal terlarut, nitrat, sulfat, fenol dan E.coli, indeks ini tidak termasuk parameter yang diperlukan untuk tujuan minuman. Walau bagaimanapun, parameter daripada ion utama, kekonduksian elektrik, dan COD telah didedahkan kepada IKABT dalam kajian ini untuk menentukan kualiti air bawah tanah untuk kegunaan tidak boleh diminum. Hasilnya, dapatan kajian ini adalah inovatif, kerana IKABT yang sesuai telah dicipta untuk menentukan kualiti air bawah tanah, terutamanya untuk aplikasi yang tidak boleh diminum. IKABT ini bermanfaat kepada komuniti, pengamal, penyelidik, penggubal dasar, sektor perindustrian dan agensi kerajaan. Tambahan pula, indeks ini dapat membantu untuk mengesan sebarang bentuk pencemaran dan pencemaran dapat dikurangkan dengan mengawal punca bahan pencemar. Sebagai cadangan untuk kajian akan datang, IKABT ini memerlukan penilaian kesihatan yang terperinci dan mengambil kira parameter penting untuk bekalan air minuman seperti yang disarankan oleh Kementerian Kesihatan sama ada ia selamat untuk kesihatan manusia.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

BGS	British Geological Survey
BIS	Bureau of Indian Standards
CCME	Canadian Environmental Quality Guidelines
CCMEWQI	Canadian Council of Minister Environment Water Quality Index
DID	Department of Drainage Malaysia
DOA	Department of Agriculture
DOE	Department of Environment
DOSM	Department of Statistics Malaysia
EPA	United States Environmental Protection Agency
EPIM	Environmental Performance Index Malaysia
FAO	Food and Agriculture Organization of the United Nations
GWQI	Groundwater Quality Index
ICPMS	Inductively Coupled Plasma Mass Spectrometry
INWQS	National Water Quality Standards
JICA	Japan International Cooperation Agency
JMG	Department of Mineral and Geoscience Malaysia
JRI	JPS River Index
MMWQI	Malaysia Marine Water Quality index
MOH	Ministry of Health of Malaysia
NSFWQI	National Sanitation Foundation Water Quality Index
NRW	Non-Revenue Water
NWRS	National Water Resources Study
OWQI	Oregon Water Quality Index
RMK	Rancangan Malaysia Kesembilan

SDG	Sustainability Development Goals
SPAN	The National Water Services Commission
UKM	The National University of Malaysia
UPM	Universiti Putra Malaysia
UN	United Nations
WAWQI	Weight Arithmetic Water Quality Index
WHO	World Health Organization
WQI	Water Quality Index

LIST OF SYMBOLS

°C	Degree Celsius
L	Liter
LCD	Liters per capita per day
mg/L	Milligram per liter
mL	Milliliter
MCM	Million cubic meters
ppm	Part per million
µS/cm	Micro siemens

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Groundwater is an essential part of the hydrologic cycle which lies in both saturated and unsaturated zone beneath the soil surface in between the soil pores and the fractures of rock formations and involves a continuous movement of water on Earth (Sato & Iwasa, 2000). Groundwater sources also consider as a main component in the natural water resources system and have been utilized since the ancient days. Groundwater sources presents in the aquifer which consists of an unconfined and confined aquifer. Malaysia is a tropical country that received an abundance rainfall which continually flows into the rivers and potentially recharging the groundwater aquifers (Shamsuddin et al., 2014). Furthermore, the groundwater recharge is consisting of precipitation of rainfall or from lakes and streams infiltrate into the soil. Rainfall as water recharges to groundwater brings many dissolves solid compared to river, stream, or lakes. In addition, floodwater retention also reliable in recharging groundwater sources.

Groundwater and surface water are basic requirement needs for all humans, animals, and plants on earth. Hence, gaining access to quality freshwater and the adequate amount is a prerequisite to achieving sustainable development. Groundwater categorized as the main source of freshwater extensively used for domestic purposes, agriculture areas, and field irrigation (Muqtada et al., 2018). Groundwater sources potentially to accommodate the clean water demands due to population expansion and urbanization. However, the excessive usage of surface water and groundwater had dwindled the quantity of clean water supply from the available water resources (Sahoo et al., 2015; Massoud, 2012).

Groundwater generally found in good quality due to filtration in the soil as compared to other water resources (Khanoranga & Khalid, 2018). However, the quality of groundwater depending on the geological structure which determined the water flow and the anthropogenic activities nearby the groundwater aquifer (Serre & Karuppannan, 2018). Meanwhile, the quality of groundwater is controlled by naturalistic activities water-rock interaction, and geology characteristics, groundwater motion, and the water residence time in the aquifer (Hejaz et al., 2020). In the other hand, water pollution may not only have an impact on the quality of water but more importantly, it may bring a threat to human health, economic development, and social prosperity (Milovanovic, 2007).

Despite the advancement in economic and technology development, World Health Organization (WHO, 2012) reported that about 1.1 billion people or one-sixth of the world population, still do not have access to a better source of drinking water. In addition, Food and Agriculture Organization (FAO, 2018) reported that the water quality is threatened in many areas around the globe due to industrial discharges, agricultural run-off and irrigation, and municipal water pollution from homes and businesses. Urbanization process, population increment, and the expansion of economic activities have eventually implicated the raising of water consumption demand (Sutadian et al., 2015).

The groundwater utilization for domestic purposes is generally constricted in the remote areas where the source from the tap water not accessible occasionally. The rural population mainly depending on groundwater sources for daily requirements where the sources of groundwater normally extracted from the shallow wells. Nevertheless, the groundwater utilization mainly prominent in the Kelantan and Perlis for public water supply (Mohammed & Ghazali, 2009). Furthermore, the groundwater sources are also used in water supply systems in the state of Terengganu, Pahang, Sarawak, and Sabah (Hafiza et al., 2019). Meanwhile, groundwater found a significant role in the public water supply system in the state of Kelantan. Approximately, 70% of the entire water supply in this state is obtained from groundwater where essentially found in the Kota Bharu areas (Hussin et al., 2015).

Furthermore, the dry spell which hit Selangor and Sarawak in 1998, assure a relief for the public where the groundwater potentially can accommodate the water demands (Fung et al., 2020). Therefore, groundwater sources significantly revealed the potential alternative water sources, and the initiative to the sustainability of groundwater development needs to be emphasized, including its quality. The emerging pollutant from the surface water potentially infiltrated in the groundwater system due to the agricultural activities and industrial. Therefore, to sustains the good quality of groundwater, the suitable index plays important role in determining the groundwater quality.

1.2 Research Background

An approximately about 99% of the water supply in Malaysia comes from rivers and streams (Jahi, 2001). The surface waters are used mainly for domestic, agricultural, and industrial activities. On the same note, Karim (2006) reported that less than 10% of water usage was from groundwater resources. From this figure, about 70% is utilized for domestic supply, approximately 25% for industrial activities and about 5% for agricultural purposes (Karim, 2006). Groundwater is used as an additional supply when surface water resources are inadequate. Thus, it is of paramount importance to sustain the high quality of both types of water resources so that they can be used for consumption in a sustainable way (Juwana et al., 2014).

Japan International Cooperation Agency (JICA, 2002) reported that there were about 103 groundwater wells that have been drilled in the state of Selangor. Most of the wells are spread around Hulu Langat, Kuala Langat, and Sepang along the Langat Basin. The Mineral and Geoscience Department (JMG, 2002) reported that there were five types of wells being categories particularly for domestic, industrial, observation, test well, and unknown. Basically, the abstracted groundwater in the Langat Basin was mainly used for industrial purposes. However, in the late 1990s, some areas which is the most rapid industrial and agricultural development and population growth area in Selangor had low water supply due to less rain falling on the catchment areas (Surip, 2003). Thus, to solve the problem, the groundwater was used as an alternative water supply. In fact, water resource shortage is one of the major challenges in Malaysia (Robertson et al., 2013).

Nonetheless, the quality of surface and groundwater can be identified in terms of its physical, chemical, and biological parameters (Loukas, 2010). In this sense, water quality can be assessed by using an individual parameter for any specific interest or by selecting dominant parameters to assess the overall quality (Huang et al., 2015). One of the effective ways to gather information on water quality is by developing suitable indices (Dwivedi & Pathak, 2007). Water quality index (WQI) is considered is one of the most useful and valuable tools to evaluate water quality. One of the advantages of WQI is that it has the potential to reduce many chemical and physical parameters into one composite component.

WQI has been proposed as early as in 1965, and since then, numerous of water quality indices (WQIs) have been developed and applied by many agencies and researchers across the globe (Gitau et al., 2016; Sutadian et al., 2016; Lobo et al., 2015; Iticescu et al., 2013; Gazzaz et al., 2012; Massoud, 2012; Chaturvedi et al., 2010, Sargaonkar et al., 2008; Lumb et al., 2002; CCME, 2001). The measurement of water quality is a pre-condition for the implementation of water protection policies and the maximum distribution of different water sources based on their uses (Kachroud et al., 2018). In most countries the concept of WQI is similar but the indices used are vary, where significant parameters are being selected compounded to the numerical rating for the evaluation of water quality. In Malaysia, Awang (2015) reported that the Department of Environment (DOE) is the authority that oversee the river quality management systems and responsible for providing the river classification standards which are termed as National Water Quality Standards (INWQS).

Asadollahfardi (2014) noted that monitoring is one of the significant elements of water quality management. In this sense, the monitoring is generally carried out by collecting relevant information on the physical, chemical, and biological categories of water quality and every category have several parameters (Swamee & Tyagi, 2007). Hence, the information obtained from these categories was used to execute a complete assessment in evaluating the quality of water bodies and for reporting its status to the water authority for further action (Sutadian et al., 2016). There are subjectivity and uncertainty involved in the steps of developing a WQI. Despite that, developing WQI is still significant for the sustainability of groundwater for future generations (Sutadian et al., 2016). Thus, the interest in search for effective WQI still continues and warrants this study to undertake further investigation.

1.3 Research Problems

The long-term reliance on clean water sources necessitates vigilance in ensuring that water supplies are sufficient to meet demand. Saimy & Raji (2015) reported that the demand for clean water supply has become one of the major issues in places such as Selangor, Kuala Lumpur, Johor Baharu, and Pulau Pinang where Malaysian natural water resources were projected to be around 25, 178 cubic meters per person in 2002. Development of infrastructure and economic growth occur the increasing of groundwater demand in the last three decades especially for Kelantan, Terengganu, Pahang including Sabah and Sarawak where shows the most depending on groundwater sources (Nampak et al., 2014). The need to sustain the clean water resources to mankind also got attention worldwide by the target of United Nation (UN) plans on Sustainability Development Goals (SDG) which an effort to overcome these serious global issues (Connor, 2015).

The issues of clean water sources become crucial since surface water is vulnerable to contamination and pollution from point and non-point sources. The polluted surface water issues raise public awareness and begin to concern on the quality of water. Illegal logging, destruction of water catchment areas and areas developments contribute to water pollution that degrades the surface water quality which consequently raise the issue of the water crisis. Human activities, urbanization, agriculture, and deforestation in Malaysia have somehow increased land-use changes and their impacts on water quality. Studies indicated that those activities have a strong association with high concentrations of water pollutants (Tu, 2011; Li et al., 2008; Buck et al., 2004; Baker, 2003). The vulnerability of surface water to contamination, on the other hand, raises serious concerns about clean water sources, particularly for drinking and domestic use. Consumption of contaminated water for daily purposes can degrade the quality of life and apparently can cause serious illness. The uncontrolled pollutant which discharged to the water body not only degrade the groundwater quality but can adverse a health problem to whom that depending on groundwater source. Kavitha et al. (2010) noted that about 80% of all the diseases in human beings are caused by water.

The water scarcity issue affects the human population due to the necessity of humans for clean water sources. With the growth of urbanization and industrialization together with the population boom, many cities in Malaysia are facing problems in supplying clean drinking water. Unfortunately, the water shortage issues keep increasing by the year and expected more serious regarding population increase and urbanization. Although groundwater sources are not widely used in many areas, it is still a major source of water in certain areas especially in areas that lack clean water supply from the tap (DOE, 2016). In addition, groundwater becomes an alternative to areas where not receive enough water sources. The implications of water shortage cause serious issues to human and other living things as well. The water shortages also affecting the agricultural sector where drought season mostly effecting to the paddy field which requires a lot of water for irrigation purposes which mainly depending on the rainfall (Shamsuddin et al., 2014).

Recently in 2019, the authority urged implementing water rationing because the dry season was hit Malaysia and four states were affected especially Selangor, Negeri Sembilan, Johor, and Kelantan due to less of average annual rainfall for a long period (Khalid, 2019). In the worst case, Malacca was facing a water shortage in the festive season due to the decrease of rainfall and the water reservoir in the dam continuing to decline where the water level in the Durian Tunggal Dam recorded 37.8 percent, followed by the Jus Dam were 66.4 percent and the Asahan Dam were 62.5 percent (Haliza, 2011). The dam water level below 29 percent considered an emergency and there was the possibility of water rationing need to be implemented. However, the water rationing in this state not implemented because of the dam water level still between the secure level. The critical issue of water shortage became apprehensive regarding the urbanization and human population increase. These inadequate water scarcities raise world attention in the objective to overwhelm this problem. Apparently, the water crisis that happened in Selangor in the year 2014 has prompted the search of groundwater supply. The need for groundwater sources as an alternative to surface water flashback to the serious water crisis where happen in Selangor in the year 1998.

The natural event such as drought season and El Nino also give a great effect on mankind in terms of seeking a clean water source. Nonetheless, during the drought seasons, groundwater becomes an alternative in supplying clean water supply to the public (Mohamed et al., 2009). The severe drought events affect the multiple water shortages and disturbance to the components of life quality of millions of citizens and occur a serious imbalance in the water (Payus et al., 2020). In addition, climate change will affect groundwater, but because of its characteristic buffer capacity, groundwater is more resilient to the effects of climate change than surface water. Therefore, in areas where climate change is expected to cause water resources to become scarcer than they are at present, the role of groundwater in water supplies is likely to become more dominant. Their buffer capacity is one of the major strengths of groundwater systems. It allows long dry periods to be bridged (creating conditions for survival in semi-arid and arid regions) and generally reduces the risk of temporary water shortages. It also smooths out variations in water quality and causes a portion of the stored water (medium-deep to deep groundwater) to be relatively insusceptible to sudden disasters, thus making this portion suitable as an emergency water source (Jac, 2012).

Currently, the quality of water in Malaysia was determined using a water quality index for surface water called DOE-WQI which had established since 1981 (DOE, 2000). However, this index is not suitable to determine the groundwater quality as the dominant possible pollutants could be different. Therefore, the need to develop the groundwater quality index becomes the main objective in current research. The determination of groundwater quality is important to ensure the groundwater sources are safe for human consumption and domestic purposes. In addition, the development of groundwater quality index in agricultural areas could give benefits to the community in terms of evaluating the quality of groundwater. Many studies found that the popular approach to measuring the quality of water is the use of a water quality index. However, due to its subjectivity and uncertainty involved in the steps of developing a WQI, there is no single WQI can be accepted applicable worldwide (Lumb et al., 2011).

Furthermore, at present, the use of indices is confined in their applicability and scope (Srebotnjak et al., 2012). Besides, studies on the quality of groundwater are still limited especially on the issues regarding pollutant and contaminant in groundwater, the different types of aquifers relationships and its origin, saline water which intrusive to the aquifers and groundwater with surface water interrelationships (Hatta et al., 2014). Apparently, the groundwater quality standards in Malaysia have still not been established (Huang et al., 2015). Besides, there is no comprehensive study been conducted on the level of physicochemical parameters in the local contexts, particularly in an agriculture area. Hence, this calls for urgent need to conduct a study particularly in the agricultural area and fill the research gap in the area.

The study area in this research focusing on the Selangor state where the most developing state in Malaysia. According to Malaysian Water Association (MWA, 2014) Selangor mainly is a rapidly developing country and has a high population distribution which is one of the factors for shortage of water supply. The water demands in the Selangor state are exceeding the water supply and become the main factor in the water scarcity in Selangor were expected to increase to 7800 MLD in 2034 from the present demand of 3900 MLD including Kuala Lumpur and Putrajaya (SPAN, 2020). The high people's migration in this state due to various job opportunities because of rapid urbanization urges the high water demands for daily usage. Therefore, the findings of the study could provide baseline data for any potential mitigation measures for policymakers, public and private agencies in addressing water quality issues. Hence, this study was intended in helping to solve the problem by developing a model of index for groundwater quality in the selected agricultural areas.

1.4 Research Questions

1. What are the dominant parameters suitable for groundwater quality index?

2. Does the groundwater quality index to be developed suitable to determine the quality of groundwater in agricultural areas?

1.5 Research Aims

The general aim of this study is to develop a groundwater quality index in the agricultural areas for domestic purposes. The specific aims of this study are:

1. To identify the main parameters for the groundwater quality in the agricultural area based on Principal Components Analysis.

2. To develop a suitable groundwater quality index in the agricultural area.

3. To evaluate the quality of groundwater in the current study using the developed index.

4. To verify the groundwater quality index by evaluating the groundwater quality in different agricultural areas.

1.6 Significance of Research

Groundwater is an alternative source to surface water that widely used nowadays. It is part of the important natural resources for ecosystem sustainability besides of surface water. It is also important in hydrological cycle sustainability which applies the same principle with surface water in the form of rainfall, hail, snow, and mist. The focus of this study was on the importance of groundwater sources for domestic usage. In addition, this study also wants to determine the suitability of groundwater to be the alternative of surface water in clean water supply. The groundwater sources are widely used in rural areas which insufficient amounts of water that normally obtains from tap water such as the isolated areas in Kelantan, Sabah, and Sarawak.

The water quality index is a method or indicator for simplify complex water quality data and making it easier to communicate with the public. Malaysia currently adapts the existing Water Quality Index (WQI) which is Water Quality Index for River Water Quality from Department of Environment (DOE), National Marine Water Quality Index for Marine and Coastal Water Quality from Department of Environment (DOE) and Drinking Water Quality Index for Drinking Water Quality from Ministry of Health (MOH). As the alternative of the clean water source, groundwater also needs for the creation of an index to assess the level of quality. According to Yunus (2009), the lack of creating the standard of quality of groundwater in Malaysia and the development of standardization for contamination of groundwater and land become a gap of study in the present status of groundwater in Malaysia. Therefore, the development of groundwater quality index is needed in terms of fulfilling the gap and as the contribution of added knowledge in the groundwater fields in Malaysia.

Hence, the new groundwater quality index in agricultural areas become a new tool to quantify and rating the groundwater quality status and the approaches of suitable treatment techniques can be created in term of enhancing the sustainability of groundwater quality. Furthermore, there are many groundwater wells that can be found in agricultural areas. Therefore, this study focused on the possibility of groundwater in agricultural areas suitable to be used for domestic purposes as an alternative to a clean water source during water rationing and the dry season. Moreover, it is reasonable to create a groundwater quality index for an agricultural area to satisfy the goal of the Malaysian Environmental Performance Index (EPIM) as part of an indicator to assess our country's environmental performance level in addition groundwater is suitable to meet the demand for clean water.

The result of this study could provide a useful insight to the policymakers, managers, and the public in addressing the issues related to water consumption for human and agriculture purposes such as designing proper planning and management of available water resource for drinking purpose. Apart from that, the finding of this study could provide information and create awareness to the public, decision-makers, and managers on the importance of the value of groundwater because the sustainability of quality groundwater is pertinent to human life. The public should be educated that the cost of degrading its quality is high and large expenses are needed for restoration. Therefore, relevant authorities and policymakers could use the data to enhance awareness to sustaining quality groundwater and this should involve schools, public forums, training courses, conferences, posters, and videos. Kavitha and Elangovan (2010) advised that since the contaminated groundwater took much time to restore, it must be protected. The water quality index is one of the most effective tools and becomes an essential indicator for the assessment and management of groundwater. Besides, good management practice for control of groundwater together with good policy and strategies is very much needed.

1.7 Limitations of Study

Although the research has reached the aims, there's were some inescapable limitations throughout this study.

1. The extensive analysis of other aspects to identify the extent of parameters that affected the groundwater quality was not carried out broadly. For example, the datum analysis and the pumping test analysis to identify the elevation and level of the contaminant in the groundwater was not carried out. Despite this study was focusing on groundwater, the detailed study on hydrogeology and geology also not covered in detail.

2. The rainfall analysis to identify the several parameters which contribute to the concentration in groundwater such as chloride and sodium also not describe in detail.

3. There was a limitation to homogenize the depth of groundwater wells in this study. The wells evaluated have a different depth that representing the shallow, intermediate, and deep groundwater. However, due to these limitations, thirteen groundwater wells were still chosen as they were suitable to meet the objective of the study which representing the groundwater in the agricultural area.

4. The interpretation of the groundwater classification is based on the suitability or level of health as it needs clinical testing which was not carried out in this study. Therefore, the details on the suitability of

groundwater to human health as described in the water quality index by the Ministry of Health Malaysia could not be stated.

Therefore, to generalize the limitation of this study, the recommendation for further research in the future potentially can expand the range of the study and fulfill the gap in developing the groundwater quality index.

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