A BRIEF REVIEW ON GROUNDWATER STUDIES IN MALAYSIA

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Abstract: Groundwater studies related to coastal and small islands in Malaysia are briefly reviewed. Perspectives are addressed as three aspects: (a) study location, where groundwater studies in Malaysia are conducted in different types of coastal and small islands (b) methods, namely numerical modeling, geophysical investigations, hydrochemical analysis and geochemical modeling applied in groundwater studies of Malaysian coastal environment and small islands; (c) types of studies, where most of groundwater studies are more focused in investigating the groundwater resources and management as well as seawater intrusion. This review revealed that main objectives in most of Malaysian groundwater studies in coastal and small islands are groundwater resources, management as well as seawater intrusion problem. This showed that groundwater studies in Malaysia are clearly needed to be increased and strategized by smart partnerships, diverse groundwater type of studies by identification of effective methods as well as capacity building improve and develop skills, expertise and knowledge in the management. Future studies should give a focus in other types studies in utilization of this resource in order to fill in the knowledge gap of groundwater to provide clear direction in sustainable development of this precious resource.

KEYWORDS: Malaysia, groundwater, coastal, small islands

Introduction

Most of coastal areas are expanding rapidly which human presence has changed the coastal environment. Coastal areas are the last discharge zone of regional groundwater flow systems. Groundwater is used extensively to supplement available surface water to meet ever increasing water demand in the world (Potter and Bennington, 2008). Small islands in Malaysia are endowed with magnificent beaches, clear waters and extensive reef formation (Praveena *et al*. 2010). In small islands, surface water is absent and groundwater is a vital source of freshwater for daily and tourism activities. Moreover, the groundwater is also an important source of drinking water in these islands (White *et al*., 2007). Malaysia receives an average annual rainfall of 2,420 mm with estimated groundwater storage about 63 billion cubic metres. The groundwater is primarily stored in two types of aquifers namely hard rock aquifers and alluvial aquifer. Hardrock aquifers are found in the north of Malaysia (Central Perak and Perlis) and Klang Valley. Crucial alluvial aquifers are located along the coastline of the east-coast states (northern region of Kelantan) and Pahang (Samsudin *et al*. 2008).

Coastal groundwater faces challenges due to lack of land for economic, ecological and social activities. These resulted in the change of coastal environment. It also alters the physical and chemical processes in the coastal groundwater system (Potter and Bennington, 2008). Threats received by groundwater in small islands are from natural and human pressures which affect both quantity and quality of groundwater in small islands. Natural pressures are such as climate change, sea level rise and variations in tropical and extra-tropical cyclones, hurricanes as well as typhoons. Pressures associated with human settlement in groundwater of small islands are such as

overpumping, tourism competition pressures with other islands and others. All these challenges and effects will be faced by the local populations, tourist industry and economy profits (Gössling, 2001).

This paper attempts to guide some of the important sources of information on groundwater studies of tropical islands that have been published in Malaysia. The published information was chosen due to accessibility factor. An overall viewpoint of Malaysian groundwater studies is to give a clear picture and direction of future investigation and exploration.

Groundwater studies conducted in Malaysia

The review analyses the groundwater studies in Malaysia in terms of perspectives of study locations, methods and types of studies.

Study Location Perspective

In Malaysian coastal groundwater, it has been used as domestic water supply. Groundwater is main source of water supply in several coastal villages in Sarawak such as Belawai, lgan, Tatau, Limbang and several other new places. Moreover in Sabah, shallow wells and small-scale tube wells have been used in Sandakan, Kota Belud and Kuala Penyu for domestic water supply. In West Malaysia, Kelantan state uses groundwater more than 70% for public water supply. Thus, the studies were designed to evaluate its groundwater quality as alternative and complimentary source of the future (Mohammed Hatta Abd Karim, 2010). According to Ismail Mohamad (2010), groundwater studies were performed in varying objectives. Generally, in coastal groundwater studies, it is vital to determine the quality and trends of water quality especially in public water supply. Apart of academic and research studies, Minerals and Geoscience Department Malaysia (JMG) has been actively involved in monitoring of coastal groundwater. This programme was initially started in 1989 and now is expanding in areas where active groundwater pumping was being carried out by state water supply authority, such as in Terengganu, Pahang, Kedah and Perlis. To date, a total of 307 and 112 monitoring wells in West and East Malaysia, respectively involve in this monitoring programme. Locations of monitoring wells include such as in Besut, Kuala Terengganu, Tumpat, Bachok, Kuala Muda, Pengkalan Hulu, Arau, Kuala Pilah, Jasin, Muar, Menumbuk and Kabong. As a general finding, coastal groundwater quality in Malaysia is good and can be used for water supply except in the confined aquifer of Tanjung Batu, Pahang. Rapid urbanization, industrialization and agricultural developments are the threats of groundwater quality in coastal groundwater.

Particularly looking at study location perspective, West Malaysia has focused in groundwater of large islands compared to small tropical islands in East Malaysia. Large islands communities in Malaysia are also relying on groundwater for their water supply besides piped water supply. Groundwater in small islands mostly in East Malaysia has limited alternatives to develop their freshwater resources. Surface water does not exist in exploitable form, fresh groundwater is the sole option to meet the water demand. The freshwater lens on islands may easily be overexploited or polluted due to dense development combined with improper management, vulnerable to climate change and the associated impacts to freshwater resources. Overdrafts of freshwater by pumping well distort the natural recharge-discharge equilibrium causes drawdown of the watertable a rise or upconing of the saltwater interface. Thus, groundwater studies in small islands are crucial to protect the freshwater resources. Thus, in such circumstances small islands groundwater resources require careful investigation and management.

Methods Perspective

In terms of methods perspective, numerical modeling has been used in groundwater studies of Malaysian coastal environment and small islands. This is most probably influenced by advantages of numerical models application in groundwater studies. Although other methods (geophysical investigations, hydrochemical analysis and geochemical modeling) have its own advantages in groundwater studies, tremendous computer technology has resulted in groundbreaking of various numerical models to dominate the complex and dynamics groundwater in small islands (Simmons *et al*., 2001). Groundwater studies in Malaysia using numerical models were done using ASMWIN-Aquifer Simulation Model for Windows, Visual MODFLOW and MT3D model, SUTRA and SEAWAT-2000 (Table 1). Most of numerical models were used to investigate the groundwater flow and transport of contaminants such as nitrate in most of groundwater studies in Malaysia. It is because septic tanks are the potential source of nitrate contamination in groundwater, due to effluent discharge through the seepage pits (Rahman and Kuan, 2004). Studies by Rahman and Kuan (2004) in Tioman Island using Visual MODLFOW and Kuan (2003) in Kota Bharu using Visual MODFLOW and MT3D model have showed numerical models are suitable to demonstrated the transport of contaminants and compliance with regulations. Numerical modeling is also used to determine the suitable pumping and recharge rates in groundwater. Such studies were more focused in tropical islands in East Malaysia done by Praveena *et al*. (2010) in Manukan Island to protect the groundwater resources. Rahman and Kuan (2004) added that investigation of groundwater is expensive and time consuming in conducting pumping test. Thus, numerical models have become a tool in groundwater investigation to determine the appropriate pumping rates suitable in tropical islands. However, according to Mohammed Hatta Abd Karim (2010), there are several limitations in terms of numerical groundwater studies in Malaysia. Limitations of environmental and meteorological data, assessment of aquifer at different depth (shallow alluvial aquifer < 30 m, deep alluvial aquifer > 30 m), knowledge of recharge and discharge areas and information of water balance are few of the constraints in conducting numerical groundwater studies. These limitations have led to various assumptions in the simulation. Assumptions were made in terms of hydrogeological part, meteorological part (e.g recharge rate), boundary and initial conditions to run the numerical models. Thus, due to these assumptions, simulation output of various scenarios by numerical model output is restricted in terms of its applications in study area.

Table 1

Hydrochemical analysis is the second most used method in groundwater studies of Malaysian coastal environment and small islands. (Table 2). This is due to the fact that it is the easiest and rapid way to determine the groundwater quality and types. The Na-Cl water type illustrates the impact of seawater intrusion. As fresh groundwater is the sole option to meet the water demand in these islands, overpumping results in seawater intrusion in these islands due to active pumping activities to extract groundwater (Praveena *et al*. 2009b). In areas with seawater intrusion, the problem is on high concentration of Cl^- which acts as a major pollutant. Water quality analysis is one of the most important aspects in groundwater studies as the water is used as public water supply. The hydrochemical analysis output can be utilized to understand the changes in groundwater quality and types due to rock-water interaction or any type of anthropogenic influence. Groundwater often consists of seven major chemical elements Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, Na^+, K^+, and SO_4^{2-}. The chemical parameters of groundwater play a significant role in classifying and assessing groundwater quality and types. Moreover, presentation of chemical analysis in graphical form makes understanding of complex groundwater system simpler and quicker. Hydrochemical analysis contains the output of

chemical parameters which can be compared with water guidelines and regulations. This approach has been used widely in coastal and small islands groundwater studies in Malaysia. According to Mohammed Hatta Abd Karim (2010) in JMG monitoring wells in Malaysian coastal groundwater, twice-a-year measurements of groundwater level and sampling were carried out. Conversely in Kelantan and Selangor states, monthly groundwater level measurements were carried out to monitor groundwater fluctuation by pumping activities at public water supply well fields as it uses more than 70% of its groundwater.

Table 2

Geophysical investigations are important in defining the subsurface geology and the associated parameters which govern the movement of contaminant plumes (Daniels *et al*. 1995). Similarly, most of groundwater studies in Malaysia using geophysical investigations have employed geoelectrical techniques in tropical islands to map the groundwater characteristics using salinity ranges or to determine freshwater/seawater interface (Table 3). Transient electromagnetic method originally designed for mineral investigation. However, it became popular for hydrogeological investigation in a very limited way over the last two decades (Christiansen *et al*., 2006). In Malaysia, transient electromagnetic method has been applied in Banting, Kuala Selangor, Yan, Tioman and Langkawi islands to determine the potential location for groundwater characterization and mapping. This method has been widely applied in Kelantan and Selangor states to delineate the potential groundwater resource. Besides, Baharuddin *et al*. (2009) applied electrical resistivity method to identify seawater intrusion in coastal-area aquifer system of Sungai Besar, Selangor. The electrical resistivity with borehole information showed the aquifers are dominated by fresh groundwater and the presence of saline water spots are due to previous floods. Saltwater intrusion in the study area is beyond 500 m of the existing shoreline. According to Abdul Rahim and Abdul Ghani (2002), the selection of which technique in geophysical method depends on the size of the site and amount of data requirement. However according to Kelly *et al*. (1989), most of geophysical studies in Malaysia are not supported by boreholes data as well as hydrogeochemical evidences. This leads to weakness of results interpretations except under simplest conditions. Combinations of information (boreholes data, hydrogeochemical evidences, topographic data) will provide the best estimates of the parameter sought. In a nutshell, the geophysical investigations provide a rapid cost effective way for hydrogeological investigation and found to be suitable in islands groundwater studies for the easy measurement phase and economically obtained. This is a cost saving way in island studies, requires a small field crew and can economically moved in island locations by small boat or air. The information about groundwater and aquifer will help in the development of a numerical model to simulate various scenarios.

Nevertheless, a key of success for any geophysical investigation is the calibration of geophysical data with geological and hydrogeological information. Although, much information may be derived from a simple assessment of the survey data, many of the geophysical methods require complex methodology and relatively advanced mathematical treatment in interpretation which limits the applications in groundwater studies in small islands. According to Samsudin (2003), a successful geophysical survey is dependent on few factors such as implmentaion of geophysical studies at an early research stage, designing a correct geophysical survey and selection of appropriate geophysical contractor.

Table 3

Groundwater studies by means of geochemical modeling are new approach in Malaysia (Table 4). So far, PHREEQC model is the only geochemical model which has been applied in groundwater samples of Manukan and Sipadan islands to demonstrate the extent of seawater intrusion geochemically in Malaysia (Aris *et al*., 2009). PHREEQC is a computer program written in the C programming language that is designed to perform a wide variety of low-temperature aqueous geochemical calculations. Advantages of using PHREEQC over other geochemical models are it is capable of handling higher ionic strengths, versatile and suitable to use in density dependent environment as such in island which could not be found in other geochemical models. PHREEQC model is able to provide an understanding of hydrochemical processes that take place in the aquifer during the freshwater–seawater mixing (Aris *et al*., 2009). The geochemical model output of PHREEQC showed the saturation indices for selected minerals and ionic concentration changes in groundwater. In Manukan Island, most of the groundwater samples are at or close to saturation with respect to calcite and aragonite. The mixing of freshwater–seawater creates a diversity of geochemical processes that has altered the theoretical composition of the freshwater and seawater mixture in the Manukan island's aquifer. In Sipadan Island, The hydrogeochemical saturation indexes (SI) were computed using PHREEQC program in order to assess the state of equilibrium between groundwater and the minerals present. The results of the analyses indicated that the groundwater had been highly enriched with ions of Na+, SO4 and Cl-, reflecting an encroachment of marine water into the aquifer. The groundwater facies in the disturbed aquifer is classified as sodium chloride (Na-Cl) water type (Aris *et al*., 2008; 2009; Abdullah *et al*., 2008).

Table 4

Types of Studies Perspective

In types of studies perspective in coastal and small islands, groundwater studies are more focused in investigating the groundwater resources and management as well seawater intrusion. Those studies were conducted by means of numerical modeling, geochemical modeling and hydrochemical analysis. Numerical models such as SUTRA and SEAWAT-2000 were used to assess the extent and location of upconing in seawater intrusion problem. For an example, study done by Praveena *et al*. (2010b) in Manukan Island using SEAWAT-2000 has been able to show that the upconing of transition zone (seawater-freshwater) is taking place at pumping well. Both of the pumping wells in Sipadan Island also showed similar upconing of saline water as a result of pumping wells on the island (Abdullah *et al*. 2010). Geochemical model, PHREEQC has been used in tropical islands (Manukan and Sipadan) to understand the geochemical process taking place during seawater intrusion. Hydrochemical analysis has been widely used to demonstrate the seawater intrusion problem via hydrogeochemistry characteristics. Studies were conducted in the aspects of groundwater quality and characteristic as it is important in public water supply and drinking water. Thus, groundwater quality and characteristic is an important phase to be highlighted in those conducted studies. It can be concluded that groundwater in coastal and small islands were studied limitedly compared to other types of studies perspectives such as in submarine discharge, tidal effect, climate change and water balance. Future undertaking of groundwater studies in Malaysia should give a focus in other types of studies in utilization of this resource.

Conclusion

The brief review highlights the conducted groundwater studies carried out in Malaysian by various methods and approaches. Perspectives such as types of studies, methods and study locations in groundwater studies were analyzed and discussed. Objectives of these studies are mainly involved groundwater resources and management as well seawater intrusion. Groundwater quality is the crucial aspect in the conducted studies to provide a good water supply and drinking water. Groundwater studies in Malaysia are still in its infancy and clearly have a long way to move forward in conducting various studies. In providing a direction on previous and future studies involving Malaysian groundwater, further detailed and site-specific information on soils, aquifer sediments and local hydrogeological conditions are clearly needed with comprehensive groundwater data to be collected, analyzed and reported in the same mode as surface water and other water-related data being publicly reported. The key issue is to increase the groundwater studies via various methods so that sustainable performance towards environment can be addressed at the outset. This is crucial step in a way to fill in the knowledge gap of groundwater studies in Malaysia involving coastal and small islands. Furthermore, smart partnership among research institutions and universities in aspects of groundwater development and management. These steps will able to diverse groundwater type of studies by identification of effective methods for the development and management of groundwater. In the same hand, capacity building through agencies, universities and research institutes can improve and develop skills, expertise and knowledge in the management of groundwater.

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TABLES

Table 1: Groundwater studies in Malaysia by means of numerical modeling

Reference	Location	Method	Objective
Ghazali *et al.* (2003)	-	SUTRA	Modeling of seawater intrusion
Rahman *et al.* (2001)	Kampung Puteh, Kota Bharu	COMES-GEO	To solve unsaturated problem in the aquifer
Tan *et al.* (2001)	Kuala Lumpur	PLAXIS	To study the lateral movement of groundwater
Abdullah (2001)	Manukan Island	SUTRA	To assess the extent of seawater intrusion
Daulay *et al.* (2001)	Tioman Island	Aquifer Simulation Model (ASM)	To investigate the quantity of water resource by looking at groundwater extractıon
Praveena *et al.* (2009b)	Manukan Island	SEAWAT-2000	To assess the extent of seawater intrusion
Praveena *et al.* (2010a)	Manukan Island	SEAWAT-2000	To assess the effect of recharge rate in groundwater resource
Abdullah *et al.* (2010)	Sipadan Island	SEAWAT-2000	To assess the extent of seawater intrusion
Rahman and Kuan (2004)	Tioman Island	Visual MODLFOW	To assess the flow and transport of contaminant (nitrate) due to withdrawal
Abdul Rahim (2002)	Tioman Island	Visual MODFLOW	To assess the flow and transport of contaminant (nitrate)

Table 2: Groundwater studies in Malaysia based on hydrochemical analysis

Reference	Location	Objective
Mohammed Hatta Abd Karim (2010)	Coastal groundwater (JMG monitoring wells)	To assess the groundwater quality
Umar *et al.* (2002)	Kuala Selangor	To characterize the groundwater types
Aris *et al.* (2008)	Manukan Island	To assess the extent of seawater intrusion using geochemical properties
Samsudin *et al.* (2008)	North Kelantan	To report the geophysical investigation
Abdullah *et al.* (2008)	Sipadan Island	To characterize the hydrogeochemistry characteristics
Yik *et al.* (2009)	Tiga Island	To characterize the hydrogeochemistry facies
Aris *et al.* (2006)	Mabul Island	To characterize the hydrogeochemistry facies and indicate seawater intrusion
Abdullah and Musta (1999)	Selingaan Island	To determine the groundwater characteristics
Abdullah and Musta (1999)	Bakkungan Kechil Island	To determine the groundwater characteristics

Table 3: Groundwater studies in Malaysia using geophysical investigation

Reference	Location	Method	Objective
Baharuddin *et al.* (2009)	Sungai Besar	Electrical resistivity	To identify seawater intrusion through subsurface profiles and coastal-area aquifer system
Umar *et al.* (2002)	Kuala Selangor	Vertical Electrical sounding	To report the groundwater resources
Ibrahim *et al.* (2002)	Telok Datoh	Electrical resistivity	To report the groundwater aquifer
Umar Hamzah. (2006)	Banting	Electrical resistivity	To report the groundwater resource
Hago Ali Hago (2000)	Bukit Jalil-Serdang	Electrical resistivity	To report the groundwater aquifer
Abdul Nassir *et al.* (2001)	Yan, Kedah	Geoelectrical imaging method	To detect the salt-water intrusion boundary
Junaidah and Jamal (1996)	Langkawi Island	Transient Electromagnetic Method	To report the potential area for groundwater resource development
Ismail and Mohd Rais (2000)	Tioman Island	Transient Electromagnetic Method	To determine the potential location for groundwater resource development
Abdullah (2001)	Manukan Island	Seismic	To determine hydrogeological characteristics
LESTARI (2005)	Sipadan Island	Seismic	To determine hydrogeological characteristics

Table 4: Groundwater studies in Malaysia using geochemical modeling

Reference	Location	Method	Objective
Aris *et al.* (2009)	Manukan Island	PHREEQC	To assess the extent of seawater intrusion using geochemical method
Abdullah *et al.* (2008)	Sipadan Island	PHREEQC	To assess the extent of seawater intrusion using geochemical method