CHAPTER 1

INTRODUCTION

1.1 Background

The terms "groundwater" and "subsurface water" have been interchangeably used to refer to water in underlying ground surface strata as depicted in the hydrologic cycle (Figure 1.1). It constitutes 22% of all freshwater on earth and is second only to polar ice (77%). Other freshwater sources are rivers and lakes (Bear et al., 1999). Groundwater is an important water source for domestic, industrial, and agricultural activities. One-third of the drinking water in the world is groundwater; however, the availability of this resource is critically low. Thus, groundwater storage may be depleted especially in areas where groundwater is heavily used (Abd-Elhamid, 2010).

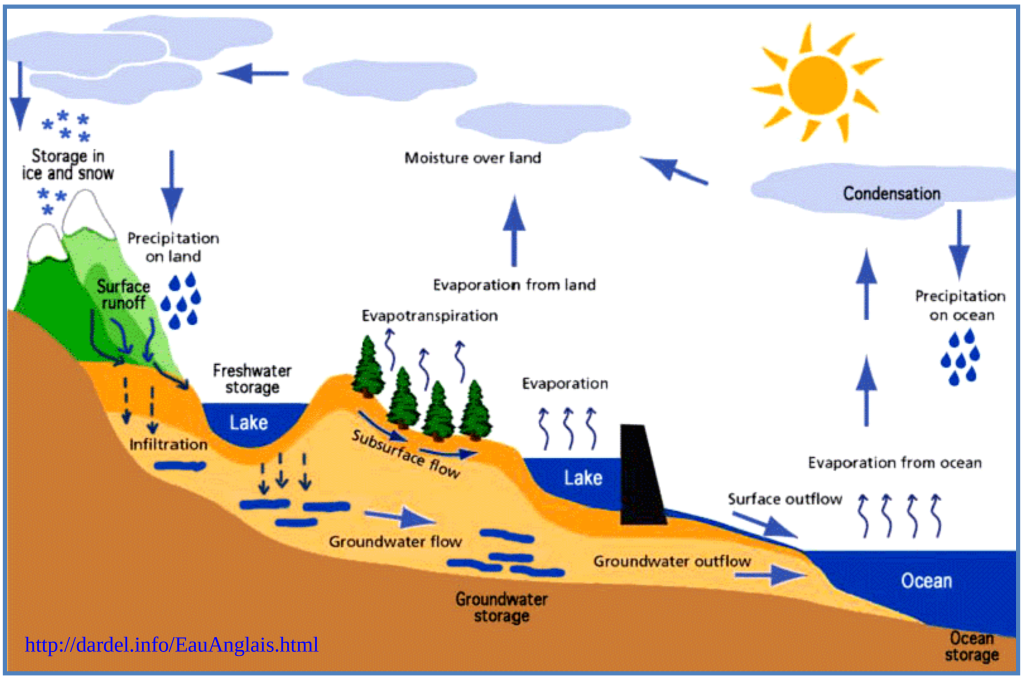

Figure 1.1: Schematic diagram of hydrologic cycle

Although groundwater is beneath the ground and is not exposed directly to surface contamination, it is typically contaminated as a result of naturally induced degradation and human activities (Todd and Mays, 2005; Abd-Elhamid, 2010). Groundwater contamination has been separated into the following four categories (Bear, 1979):

Environmental contamination is a result of groundwater flow through different geological stratigraphies (this phenomenon is closely associated with seawater intrusion in coastal areas).

Domestic pollution is attributed to sewer leakage, septic tank effluent percolation, infiltration of rain into sanitary landfills, and artificial water supply well recharging by using treated sewage containing biological contaminants.

Industrial pollution is caused by improper disposal of sewage that contains heavy metals, non-deteriorating compounds, and radioactive materials.

Agriculture contamination originates from irrigation water that contains fertilizers, salts, herbicides, and pesticides. This water infiltrates the ground surface and replenishes the water in the aquifer.

Environmental contamination is the major contributor to groundwater contamination and most profoundly affects the coastal area because the resultant seawater intrusion from proximity to the sea consequently deteriorates coastal groundwater quality. Groundwater salinity can increase to levels that often exceed acceptable drinking water and agriculture water standards. Coastal aquifers used for water supply and agricultural activities are thus endangered (Abd-Elhamid, 2010). According to Bear et al., (1999), saltwater intrusion into coastal aquifer is caused by:

a) Seawater intrusion

b) Over-abstraction of the aquifers

c) Seasonal changes in the natural groundwater flow

d) Tidal effects

e) Barometric pressure

f) Seismic waves

g) Dispersion

h) Climate change (global warming and rise in sea-level)

Groundwater quality deterioration in coastal areas worldwide is always being associated with seawater intrusion into coastal groundwater aquifers. Seawater intrusion is considered a normal global phenomenon (Hahn, 1991) and is a major factor in freshwater and saltwater imbalance in groundwater aquifers. This phenomenon is the result of changes in seawater levels and groundwater tables.

Coastal seawater intrusion may be caused by either a natural or forced phenomenon. The former is a result of natural tide transgression (Bear and Cheng, 2010a); whereas the latter is a result of groundwater extraction activities that 'force' saline water into the freshwater aquifer (Freeze and Cherry, 1979). The rate of seawater intrusion induced by a forced phenomenon is greater than that induced by a natural phenomenon when groundwater extraction is excessive (Bear and Cheng, 2010b). However, intrusion rate also tends to increase when the sea level rises, which eventually enhances salinization and decreases freshwater availability (Essink, 2001). Seawater intrusion is a daily, naturally occurring event that must be considered in coastal aquifer planning and management (Bear and Cheng, 2010b) because it is a major constraint in the utilization of groundwater in coastal aquifers (Darnault and Godinez, 2008; Bear and Cheng, 2010b).

Water demand has increased because of additional socioeconomic activities attributed to population growth and urbanization. Land cover and land use change as living standards in the residential, commercial, and industrial sectors improve. Natural forest habitats are commonly converted into plantation areas that provide commercially important commodities. Thus, coastal alluvial aquifers have been explored as an additional water resource to meet the increasing freshwater demand of the growing population.

Coastal areas in Malaysia are increasingly important to the country's socioeconomic well-being. First, coastal areas contain several potential groundwater resources (Suratman and Awang, 1998). Second, oil palm is mostly cultivated in coastal regions.

The vast shoreline, which extends to over 4800 km, is constantly threatened by seawater intrusion. Studies report that a considerable portion (over 30%) of the shoreline has experienced severe erosion (Syed Alwi, 1992). This problem threatens natural habitats (mangroves and peat swamps) along numerous coastal areas (Ann, 1996). Sustaining natural habitats in coastal areas can help stabilize the shoreline and recharge groundwater, thereby preventing seawater intrusion. However, this idea has not been fully realized (Bann, 1998; and UNEP, 2007).

The effect of climate change on socio-economy in the 21st century has generally been addressed (IPCC, 2001). However, its effect on sea level increase in coastal regions requires particular attention because it directly threatens the integrity of groundwater quality and oil palm activities. Thus, the current effect of seawater intrusion on groundwater systems and the deterioration of these systems as a result of salinity are examined with respect to socioeconomic planning.

The issues described above form the background of this study. This research is progressive and in parallel with the government's effort to enhance groundwater supply and the oil palm industry in coastal regions. Therefore, this study assesses the groundwater salinity by using a technique that integrates geo-electrical and geochemical methods - in the coastal regions of the Carey Island in Selangor, Malaysia. This approach helps to correlate salinity "toxicity" to agriculture, especially for oil palm cultivation. In addition, this technique is combined with the surface and subsurface hydrogeology study.

1.2 Significance of the study

The significance of the study is threefold: First, the hydrogeological characteristics of the study area, which have not been discussed in detail by past researchers (Ngah, 1988; Tahir and Abdul Hamid, 2003; Japan International Cooperation Agency (JICA) and Department of Mineral and Geosciences Malaysia (DMGM), 2002; and Ismail, 2008), are identified. It is important to examine the differences or similarities with regards to the hydro-geological characteristics from the aspect of groundwater occurrence and hydro-geological subsurface between the island and the mainland. These issues are therefore new, hence important to the study by filling up the knowledge gap currently not explored. The identification of the current hydrogeological characteristics of the island while the community is at its peak of socioeconomic prosperity is critical because the island constitutes 6% of the Langat Basin area. The hydrogeological setting of the island may be similar to that of the mainland. Therefore, groundwater occurrences in the study area are addressed in relation to the origin of recharge either from natural precipitation on the island or base flow from the Langat Basin in the mainland.

Second, Carey Island is essentially the only island in Malaysia that relies on oil palm cultivation as a major source of income. Thus, it is important to address this issue because the use of groundwater for cultivation may conflict if seawater intrusion limits extraction of the groundwater. Further, this study determines the boundary between fresh and saline groundwater based on their size and distribution. Therefore, this study directly relates to the government's effort to re-develop groundwater resources in the island according to the 10^{th} Malaysia Plan (GOM, 2010).

Third, three methods, namely, geochemical, geophysical, and integrated methods (Bear and Cheng, 2010b), are commonly used to assess groundwater salinity as a result of seawater intrusion. The most frequently used among these methods is the technique that integrates geophysical and geochemical methods, which has not been previously utilized to investigate the effect of seawater intrusion on groundwater salinity to oil palm cultivation.

1.3 Aims and objectives of the study

The surface and subsurface hydrogeology characteristics of the island, especially those of the area susceptible to seawater intrusion from the Straits of Malacca, have not been investigated thus far. The groundwater characteristics in the study area have not been studied via geo-electrical and geochemical correlations. The oil palm industry is the main source of income for the inhabitants of the study area, and efforts to re-develop groundwater resources are currently ongoing. Examining the deteriorated groundwater quality of groundwater resources and agriculture (oil palm) activities as a result of salinity caused by seawater intrusion is important, and the integrated technique used in this study is unique because it has not been attempted previously. Surface and subsurface hydrogeology characteristics were incorporated in the assessment of seawater intrusion effect on the groundwater aquifer in the study area.

The objectives of the research are

a) to determine the surface and subsurface hydrogeology characteristics that can influence groundwater salinity,
b) to study the geochemical characteristics of the groundwater aquifer,
c) to determine subsurface resistivity distribution in the study area,
d) to determine the source of salinity in groundwater aquifers by using the geo-electrical-and-geochemical integrated method,
e) to establish the correlation between subsurface resistivity and geochemical data for determining groundwater salinity degree (fresh, brackish, and saline),
f) to establish the correlation between subsurface resistivity and geochemical data for determining groundwater salinity suitability to agriculture cultivation, and

g) to evaluate the groundwater salinity impact towards agricultural cultivation.

1.4 Scope of works

The objectives discussed above are addressed by the scopes of works listed as follows:

a) A review of previous literature provides basic information that helps define the subsurface hydrogeology characteristics of the groundwater aquifer system in the study area.

b) The study area is located on the west and south of Carey Island that is facing the sea where seawater intrusion directly occurs.

c) Fourteen monitoring wells are constructed in the study area. A general survey, drilling, soil sampling and testing, and wells construction are conducted on these wells.

d) According to the procedure outlined in BS 5930 (1999), this study used the rotary wash boring machine for drilling the holes to construct monitoring wells.

e) Soil tests (particle size distribution, Atterberg limit, and moisture content) are conducted in accordance with BS 1377 (1990).

f) Total station equipment (model GPT-3100N Series Top Con) is used to determine the elevation of the monitoring wells.

g) Local precipitation data and tide conditions are obtained from the related governmental agencies.

h) The groundwater table provides the quantities and physical characteristics [conductivity, salinity and total dissolved solids (TDS)] of the groundwater in the monitoring wells as determined by using EC300 YSI equipment.

i) Analyses of major cations and anions via Perkin Elmer inductive coupled plasma and Dionex ion chromatography (Model ICS2000) according to the American Public Health Association standard method (APHA, 2005).

j) Subsurface resistivity is measured by using ABEM Terrameter SAS4000 with an ES10-64 electrode selector.

k) Raw data of subsurface resistivity are processed by using the SAS 4000 utilities software.

l) Res2Dinv software is used to obtain true subsurface resistivity distribution in measured resistivity data analysis.

m) The time lapse resistivity tomography (TLERT) technique is used to determine the source of salinity in groundwater aquifers.

n) The integrated method that combines geo-electrical and geochemical approach is used to evaluate groundwater salinity degree (fresh, brackish, and saline) by correlations the groundwater chemistry and subsurface resistivity.

o) The relationship between groundwater chemistry and subsurface resistivity is statistically analyzed via kurtosis, skewness, root mean square, and linear regression.

p) The results of previous investigations into the suitability of salinity for oil palms are considered in the assessment of the current salinity effect.

1.5 Outline of the thesis

This thesis is organized into seven chapters. Chapter 1 identifies the aims and objectives of the research.

Chapter 2 presents a background on the effect of seawater intrusion on coastal aquifers, oil palm plantation in coastal areas, oil palm physiography, and the hydrogeological conditions and socioeconomic status of the selected study area. This chapter is separated into four main sections. The first section reviews past studies on hydrogeological effects of seawater intrusion on the coastal area and discusses the applications of seawater-intrusion detection methods in several case studies. The knowledge gap with regard to the application of these methods to seawater intrusion in coastal areas is also discussed. The second section reviews on groundwater system in coastal area. This section discusses the hydrogeology and geology of the study area based on previous literature. The third section, however, reviews the agriculture activities in coastal area in Malaysia. This section reviews oil palm plantation in Malaysian coastal areas as well as discusses oil palm physiography and salinity tolerance. The fourth section discusses groundwater resources, current groundwater usage, agricultural activities, land cover, and land use patterns in the study area. Chapter 3 presents the methodologies used in this study, including surface and subsurface hydrogeology and subsurface resistivity study.

Chapter 4 lists the surface and subsurface hydrogeology characteristics of the study area. Geological, hydrological, and hydrogeological investigations are conducted. Groundwater quality and the groundwater table are monitored on a long-term basis based on hydro-chemical data. The effects of rainfall and tide condition on groundwater tables are also explored in this chapter.

Chapter 5 discusses the geochemical results and resistivity surveys that assess the hydrogeological conditions of the study area. The distributions and locations of the fresh, brackish, and saline water boundaries in the aquifer are determined based on the correlation between geophysical and geochemical data. The statistical analysis of the data and the on-site physical experiment are also discussed. This chapter also provides the TLERT measurements to assess the dynamic changes in groundwater salinity as a result of seawater intrusion.

Chapter 6 assesses the effect of groundwater salinity to oil palm cultivation in the study area. 3-D resistivity and conductivity slice images convey groundwater salinity distribution in the groundwater aquifer of the study area. This chapter explores the limited capability of available freshwater to meet agriculture demand given its salinity at different surface and subsurface hydrogeology characteristics.

Chapter 7 presents the main conclusions of the study and recommendations for further studies.