CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

This chapter review past literatures which are pertinent to the seawater intrusion into groundwater aquifers, groundwater occurrence and socioeconomic activities of coastal areas. Summary of flowchart on the literature reviews conducted in this study is given as in Figure 2.1.This chapter is divided into four main sections. The first section reviews past studies on the seawater intrusion in coastal areas and its effect to groundwater aquifers, while the second section is on the groundwater system in coastal areas. The third section, however, reviews the agriculture activities in coastal area of Peninsular Malaysia which includes the oil palm plant physiography and the effects of salinity towards the plant. The last section reviews the socioeconomic activities, history of groundwater resources and land cover of the selected study area (Carey Island). The reviews highlighted the studies that had been done and the scope that needs further investigations. The summary section concludes the literatures that have been reviewed.

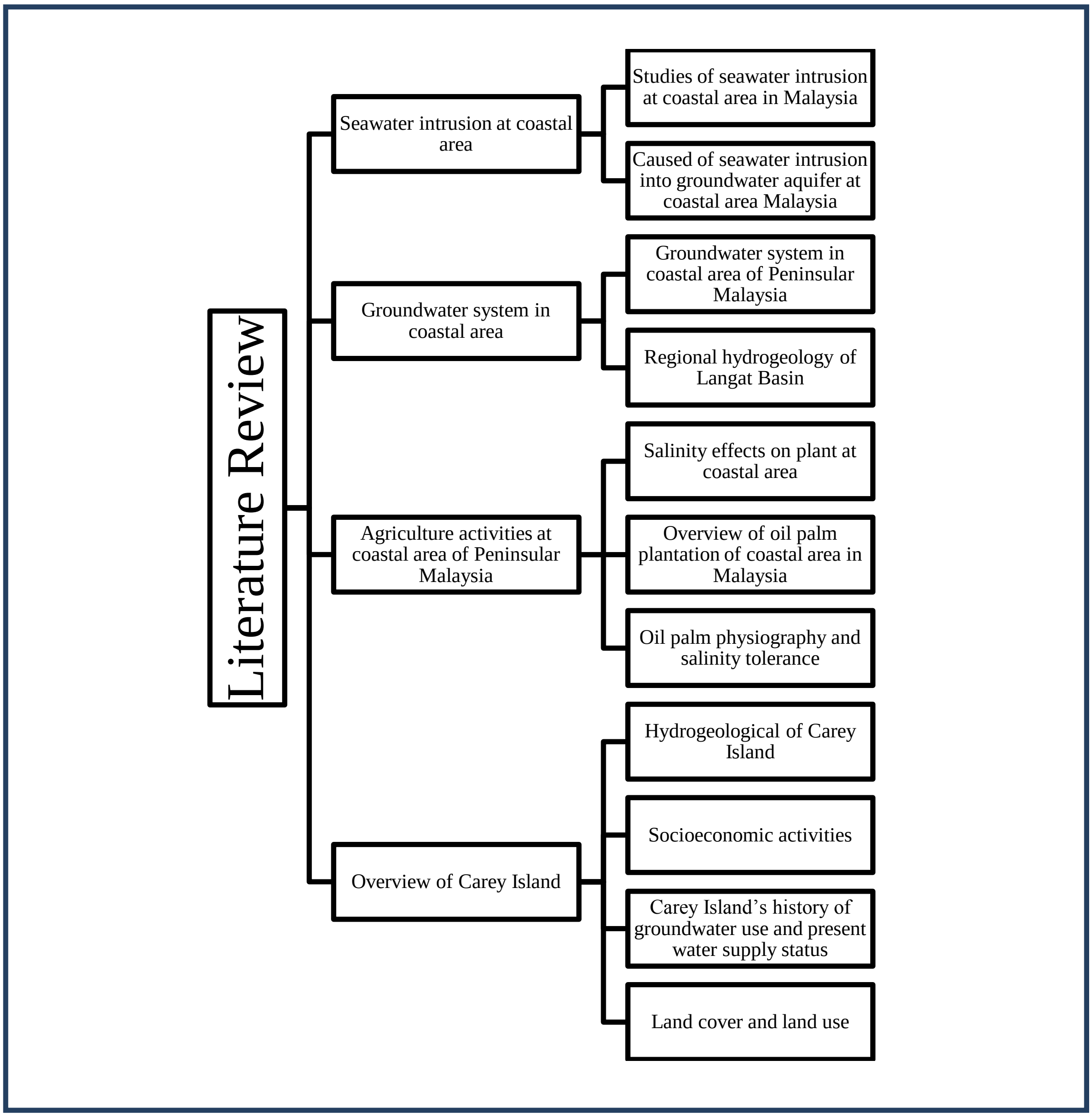


Figure 2.1: Flow chart of literature review on impact of seawater intrusion to coastal activities

2.2 Seawater Intrusion at coastal area

Seawater intrusion is a landward migration of seawater into freshwater coastal aquifers (Ivkovic et al., 2012). Seawater intrusion can be caused by natural and human-induced factors such as excessive groundwater extraction, groundwater recharge variations, sea-level rise and tide effects (Todd, 1974, Bear et al., 1999, Essink, 2001, El-Hamid, 2010, Ivkovic et al., 2012). Seawater intrusion can have an impact on coastal area activities such as agriculture, groundwater supply and aquaculture (IPCC, 2007). Among the two critical socioeconomic activities of coastal area that will be affected by seawater intrusion are groundwater supply and agriculture. Fresh groundwater either in small islands or the mainland of coastal area can be contaminated with saline groundwater through seawater intrusion from the daily tidal activities. These require special attention in the fresh groundwater planning and management (Bear and Cheng, 2010b).

Researchers use the geo-electrical method to study seawater intrusion into groundwater aquifers in the coastal areas. For example, Edet and Okereke (2001) used the geo-electrical method and geochemical data to examine the extent of seawater intrusion in shallow aquifers (with depths less than 300 m) beneath the coastal plains of the Southeastern Nigeria. Similarly, Benkabbour et al., (2004) used the geo-electrical method to characterize seawater intrusion in the Plioquaternary consolidated coastal aquifer of the Mamora Plains in Morocco. In another work, Di Sipio et al., (2006) used the geo-electrical method and geochemical data to obtain a better salinity profile of the groundwater system in Venice estuaries. An interesting work from Awni (2006) employed the two-dimensional (2D) geo-electrical method to detect sub-surface freshwater and saline water in the alluvial shoreline of the Dead Sea in Jordan. Researchers have even integrated the geo-electrical and the hydro-geochemical methods to delineate seawater intrusion. Work of Sherif et al., (2006) is one such example, which was conducted in Wadi Ham, UAE. In addition, researchers also employ field survey to investigate saltwater intrusion. For example, Adepelumi et al., (2009) used the vertical electrical sounding survey to delineate seawater intrusion into the Lekki Peninsula freshwater aquifer located in Lagos, Nigeria.

There are numerous other works, which have integrated two methods to investigate saltwater intrusion. For example, Sikandar et al., (2010) integrated a geo-electrical resistivity survey and geochemistry measurements to investigate groundwater conditions in Pakistan. In a very interesting work, Sathish et al., (2011) combined the geo-electrical and the geochemical methods to assess the zone of mixing between seawater and groundwater in the coastal aquifer in the South Chennai, in Tamil Nadu, India. Ebraheem et al., (2012) conducted a 2D earth resistivity imaging survey in the Wadi Al Bih area in the Northern UAE to determine the potential of the quaternary aquifer and its groundwater quality. Another work that combined two methods was conducted by Khalil et al., (2012), where they used the geo-electrical method and time-domain electromagnetic method to access seawater intrusion into the groundwater system in the northwestern coast of Egypt. Similarly, Chekirbane et al., (2014) used the time-domain electromagnetic method with geochemical tracers to explore the salinity anomalies in a small island coastal aquifer in north-eastern Tunisia. Shalem et al., (2015) used the geo-electrical method and boreholes data to examine the extent of seawater intrusion in shallow aquifers beneath the coastal plains of the Eastern Mediterranean. Frances et al., (2015) used geo-electrical and electromagnetic hydrogeophysical methods to detect the freshwater–saltwater interface along the coastline in Algarve, Portugal.

Findings from previous work suggest that the combination of the two methods is the most suitable to examine the extent of seawater intrusion into groundwater aquifer at coastal area.

2.2.1 Studies of seawater intrusion at coastal area in Malaysia

Study of the seawater intrusion status at low lying coastal area in Peninsular Malaysia was conducted by Ismail et al., (2007). The study involved groundwater sampling and geo-chemistry analysis. Chemical analysis of the groundwater samples showed more than 90% of anions content was contributed by chloride. The highest anions value was recorded in Penang state (7,500 mg/L) followed by Johore (2,700 mg/L) and Kelantan (180 mg/L). As for the Western alluvial coastal area, Selangor state recorded the highest anions content of 165 mg/L.

These results showed that the seawater intrusion is the source of salinity in the groundwater of coastal areas. However, one can conclude that the study represents only preliminary information about the status of seawater intrusion in the Peninsular Malaysia because their work used a limited number of monitoring wells for a very large study area. It should be noted that studies on the impact of the seawater intrusion require to determine the saline-freshwater boundary, and requires huge numbers of geochemistry data acquisition.From the above discussion it can be concluded that there is a lack of geochemistry data for the Peninsular Malaysia; therefore, one needs to conduct a comprehensive study on the impact of the seawater intrusion in groundwater aquifer.

The limitation on the requirement for huge numbers of geochemistry data in seawater intrusion assessment can be overcome by utilizing integrated methods (Maillet et al., 2005; Sathish et al., 2011). Various researchers in Malaysia had applied geochemical and geophysical methods for the seawater intrusion assessment (Hamzah et al., 2000, Mohamad et al.,2001, Mohamad, 2002, Baharuddin et al., 2001, Samsudin et al., 2002, Jumary et al., 2002, Hamzah et al., 2006 and Samsudin et al., 2008).

The studies on the assessment of seawater intrusion to groundwater aquifer in Pekan Nenasi coastal area in the state of Pahang, Malaysia had been conducted by Mohamad et al., (2001) and Mohamad (2002). Geo-electrical method and geochemistry data were used to assess seawater intrusion that caused the deterioration of groundwater quality in the area. Geophysical mapping of seawater intrusion in Kerpan coastal area of Kedah state was conducted by Baharuddin et al., (2001) and Samsudin et al., (2002).Vertical geo-electrical sounding and two-dimensional (2-D) geo-electrical resistivity imaging techniques were used to assess the groundwater salinity condition in this area. These studies exclude the integration with geochemistry data to confirm the salinity condition of the groundwater. A combination geo-electrical and geochemistry methods to assess the degree of groundwater salinity at the coastal area of Kuala Selangor in the state of Selangor, was carried out by Jumary et al., (2002). The study utilizes the water type classification as saline (less than 5 Ω.m), brackish (5 to 100 Ω.m) and freshwater (more than 100 Ω.m). The classification was used to mapping and profiling the degree of groundwater salinity in this area. The combination of geo-electrical and geochemistry method to relate the groundwater salinity condition with seawater intrusion near Banting coastal area Selangor was studied by Hamzah et al., (2006). Combinations of geochemical and geo-electrical methods also were used to study the salinity of groundwater aquifers along the coastal area of north Kelantan by Samsudin et al., (2008).

Study on seawater intrusion in north Kelantan Malaysia by geo-electrical method was conducted by Islami (2009) and Islami (2010). This study interpreted low resistivity (less than 7 Ω.m) as seawater. The study of seawater intrusion in Carey Island, Selangor, Malaysia was carried out by Igroufa et al., (2010). This study maps the subsurface salinity distribution in Carey Island due to seawater intrusion by using geo-electrical method. The presence of a low resistivity zone (less than 3 Ω.m) in the two-dimensional resistivity images was the main characteristic of the resistivity survey. This was considered as being associated to seawater intrusion from the Straits of Malacca. Their studies on seawater intrusion into groundwater aquifer were conducted without the support of any geochemistry data.

Studies on seawater intrusion in small coastal islands of Malaysia have been conducted by several previous researchers. Numerical simulation techniques using modelling software have been conducted by Praveena et al., (2010a), Praveena et al., (2010b), Praveena et al., (2011) and Praveena et al., (2012) in Manukan Island of Sabah, Malaysia. Different scenarios of varying recharge and pumping rates based on threats received by Manukan Island were investigated using SEAWAT modeling. The findings from the above research works helped in sustainable groundwater management; in addition, it contributed in effective analysis of water policy, planning, and management. Therefore, it can be concluded that study of seawater intrusion helped to overcome current as well as future seawater intrusion problem in the Manukan Island of Sabah, Malaysia.

Geochemistry interaction studies on seawater intrusion in groundwater at Manukan Island of Sabah were conducted by Aris et al., (2012) and Aris et al., (2013). These studies attempted to characterize the chemistry of an impacted zone of seawater intrusion in the costal island using statistical approach and hydro-chemical model package for a few monitoring well established in the island. The results of these study revealed three main processes associated with seawater intrusion event; aquifer salinization, cation exchange process and redox sequences.

A study on numerical model of seawater intrusion in a semi-confined aquifer in the lowland area of Langat Basin, Selangor, Malaysia was conducted by Nusari et al., (2013). This study simulated the extent of seawater intrusion into the aquifer system in the lowlands of Langat Basin as a result of continuous and intense groundwater exploitation for industrial processes between 2001 and 2010. A 3-D finite difference numerical model based on SEAWAT-2000 was applied to investigate seawater intrusion. The simulation results showed that the aquifer system was affected by seawater intrusion and that most of the main aquifer suffered seawater intrusion during the simulation period. The calibrated model was used to predict the extent of seawater intrusion into the aquifer system for 35 years (2011 to 2045). The model results showed that almost the whole main aquifer (fourth layer aquifer) would be encroached by seawater with high chloride content within the next 35 years if the current rates of groundwater exploitation (more than 80,000 m^3/day) were to continue.

2.2.2 Cause of seawater intrusion into groundwater aquifer at coastal area of Malaysia

The study of seawater intrusion into groundwater aquifer at Pekan Nenasi Pahang coastal area which were conducted by Mohamad et al., (2001) and Mohamad (2002) showed that excessive groundwater pumping has been identified as the major contribution to seawater intrusion in this area. The assessment of groundwater aquifer salinity condition at Kerpan coastal area of Kedah by Baharuddin et al., (2001) and Samsudin et al., (2002) showed the increased of groundwater salinity towards the coastline and it was believed to have a direct relationship with the seawater intrusion due to the daily tidal activity. At the coastal area of Kuala Selangor in the state of Selangor, seawater has been detected to intrude into the groundwater aquifers as far as 4 to 6 km from the coastline (Jumary et al., 2002) also due to the seawater intrusion from daily tidal activity. Study on the groundwater salinity condition near coastal area of Banting, Selangor by Hamzah et al., (2006) showed the occurrence of brackish and saline groundwater was due to the seawater intrusion from excessive pumping activities. The study on salinity of groundwater aquifers along the coastal area of north Kelantan by Samsudin et al., (2008) indicated that the second aquifer which consisted of fresh water and saline water interface was located as far as 6 km from the coast. High chloride content in the second aquifer suggested that the salinity of the groundwater was caused by trapped ancient seawater intrusion. Other studies in North Kelantan by Islami (2009 and 2010) revealed that groundwater salinity was caused by trapped ancient seawater. A study on seawater intrusion in a small coastal island by Praveena et al., (2010a and 2010b) revealed that excessive groundwater pumping caused seawater intrusion.

As from the literatures studies, saline groundwater has occurred in several places of the coastal area in Malaysia. The saline groundwater may come from the seawater which intruded into the groundwater aquifer due to the daily tidal activities and accelerated by the excessive pumping activities. Most of the studies focused on the assessment of seawater intrusion to the groundwater condition in their area. The focus of previous studies was salinity mapping of the groundwater aquifers. However, the impact of seawater intrusion and the current groundwater status towards the socioeconomic activities such as agriculture of the coastal area in Peninsular Malaysia is still lacking.

2.3 Groundwater system in coastal area

Groundwater occurrences in small islands and mainland coastal areas can be distinguished by recharge sources and interface boundaries (fresh-saline boundary) shape (Fetter, 2002; Bear and Cheng, 2010a). Small islands are defined as the land area which covered less than 10 km^2 (Dijon, 1983; White and Falkland, 2010). In small islands, the groundwater aquifers mainly received water source from direct precipitation. Meanwhile in the mainland coastal area, groundwater aquifers received recharge sources from direct precipitation and base flows (Fetter, 2002).The primary water resources in small islands are contributed by freshwater lens (White and Falkland, 2010). The fresh groundwater lenses shape was caused by the difference between the fresh and saltwater densities. Fresh groundwater has lower density than the saltwater, thus the fresh groundwater always float on top of the saltwater (Fetter, 2002; Bear and Cheng, 2010a).Therefore, the interface fresh-saline boundary of the small islands shows a horizontal boundary shape. Meanwhile, the interface boundary of the mainland groundwater flows always shows an inclination of a boundary shape. The difference in the occurrence of fresh groundwater between coastal areas in small islands and mainland is shown in Figure 2.2. It also showed a number of typical cross sections with the recharge source and interface boundaries (fresh seawater boundary) in coastal aquifers under natural conditions (a, b, c) and with pumping (d).

The existence of freshwater lens occurrence in small islands has been reported by Vacher (1978), Ayers and Vacher (1986), Oberdorfer et al., (1990), Schneider and Kruse (2003), Schneider and Kruse (2005) and White and Falkland (2010). Freshwater lens can also occurred in perched unconfined aquifer as reported by Todd and Mays (2005), Fetter (2002), Younger (2007) and Bear and Cheng (2010b). The observation from the literature studies generally simplifies the types of freshwater lens into two categories. The first type is freshwater lens which float on top of saline water due to the differences in water densities. This is usually occurred in small islands and atolls. The second type is freshwater lens which sited on impermeable layer in unconfined aquifer. The two type of freshwater lens occurrence is illustrated in Figure 2.3.

Perched groundwater aquifer can be defined as freshwater lens. The surface water that infiltrates into the groundwater system is trapped in the impermeable layer to form the perched groundwater aquifer. Perched groundwater aquifer is isolated from the main saturated groundwater zone. The isolation of the groundwater body is caused by the presence of un-continuous impermeable layer in the unsaturated zone situated above the main saturated groundwater zone (Todd and Mays, 2005; Younger, 2007). The perched aquifer occurrence in unconfined aquifer is as illustrated in Figure 2.3. Perched aquifers in alluvium coastal area are rarely occur due to the high groundwater tables normally found in the low lying coastal area.

Freshwater lens thickness can be affected by several factors where the greatest effect is due to the geological formation (Fitts, 2005; Fetter, 2002). Geological formation comprising heterogeneous materials (various grain sizes) can create variable porosity materials. This, however, led to the existence of various hydraulic conductivities of the aquifer material. Transgression tide (seawater) penetrates materials with high hydraulic conductivity more easily than those with low hydraulic conductivity (Oberdorfer et al., 1990; White and Falkland, 2010). This will cause the decrease in the freshwater lens thickness. Freshwater lens thickness can also be affected by vegetation variation and terrain elevation that influences groundwater recharge rate at the site (Schneider and Kruse, 2003; Schneider and Kruse, 2005).

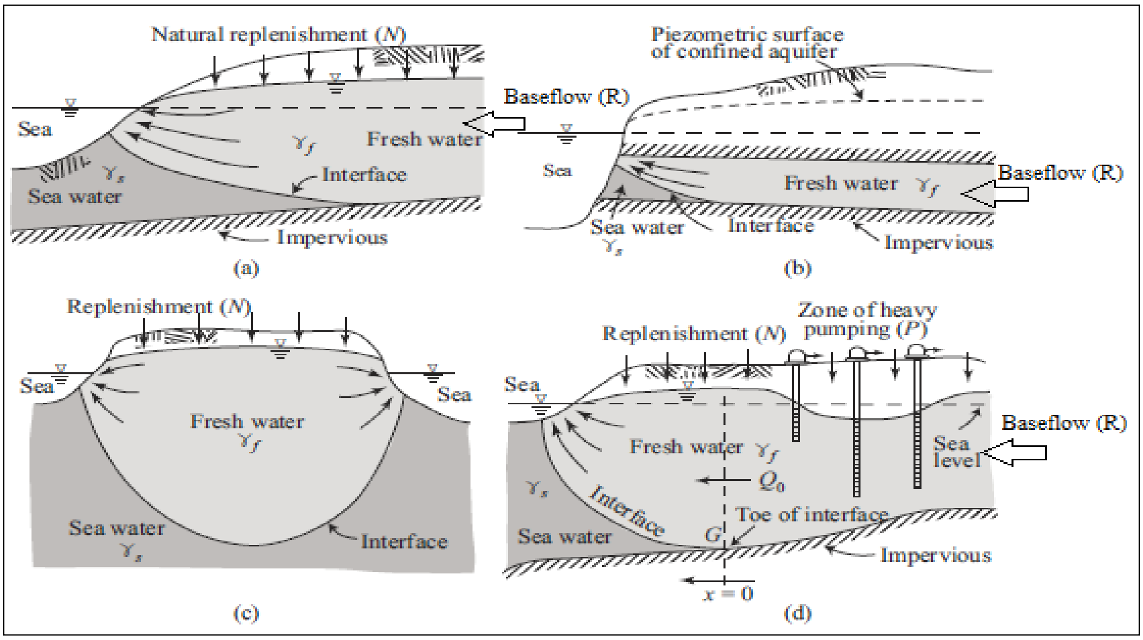


Figure 2.2: Typical vertical cross sections of seawater intrusion in coastal aquifers. (a) Unconfined aquifer with replenishment; (b) Confined aquifer; (c) Freshwater lens in an island; and (d) Unconfined aquifer with pumping. Note that γ_f and γ_s represent the densities of freshwater and seawater, respectively (Bear and Cheng, 2010b with modifications)

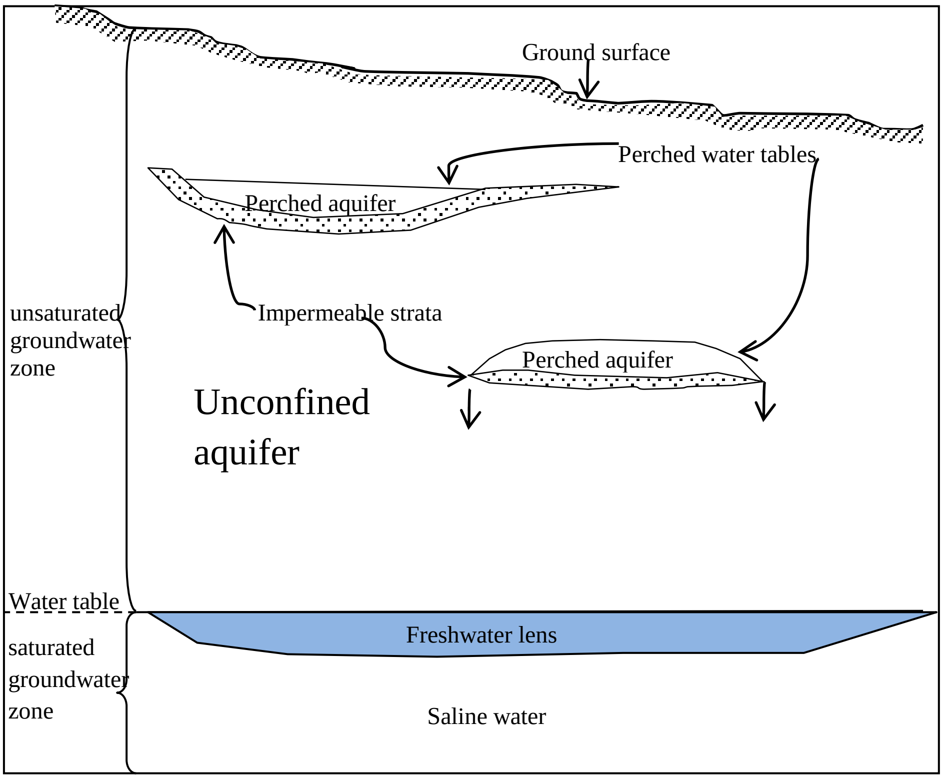


Figure 2.3: Freshwater lens in aquifer (Todd and Mays, 2005)

2.3.1 Groundwater system in coastal area of Peninsular Malaysia

The coastal area has been identified as having the largest prospect for groundwater supply in Peninsular Malaysia. The groundwater map (Figure 2.4) illustrates the groundwater aquifer prospect in the Peninsular of Malaysia. It can be divided into four categories, namely, alluvial, limestone, meta-sedimentary, and igneous aquifers. Alluvial aquifers are located along the coastal areas of the east and west coast of Peninsular Malaysia. Normally, the aquifer is thicker and wider in the east coast than in the west coast. Comparing to the other categories of aquifer, alluvial aquifer is highly productive by generating an average of 30 to 50 m^3/hr groundwater yield. The water quality is suitable for domestic purposes, with some localities having brackish water. The alluvial aquifer is vulnerable to seawater intrusion due to its close proximity to the sea (Suratman and Awang, 1998).

Seawater intrusion can cause deterioration in the groundwater quality by changing the groundwater salinity. The classification of groundwater salinity can be divided into three types namely; fresh, brackish and saline. The classification according to TDS values were proposed by Fetter (2002). TDS values less than 1,000 mg/L are classified as freshwater. TDS values ranging from 1,000 mg/L to 10,000 mg/L are classified as brackish water and values more than 10,000 mg/L are classified as saline groundwater. According to Interim National Water Quality Standards for Malaysia (Department of Environment Malaysia, 2010), TDS values of less than 1000 mg/L required no treatment for water supply.

Among the coastal areas in Peninsular Malaysia that has been identified as having the most impact by seawater intrusion to the socioeconomic activities is Langat Basin.

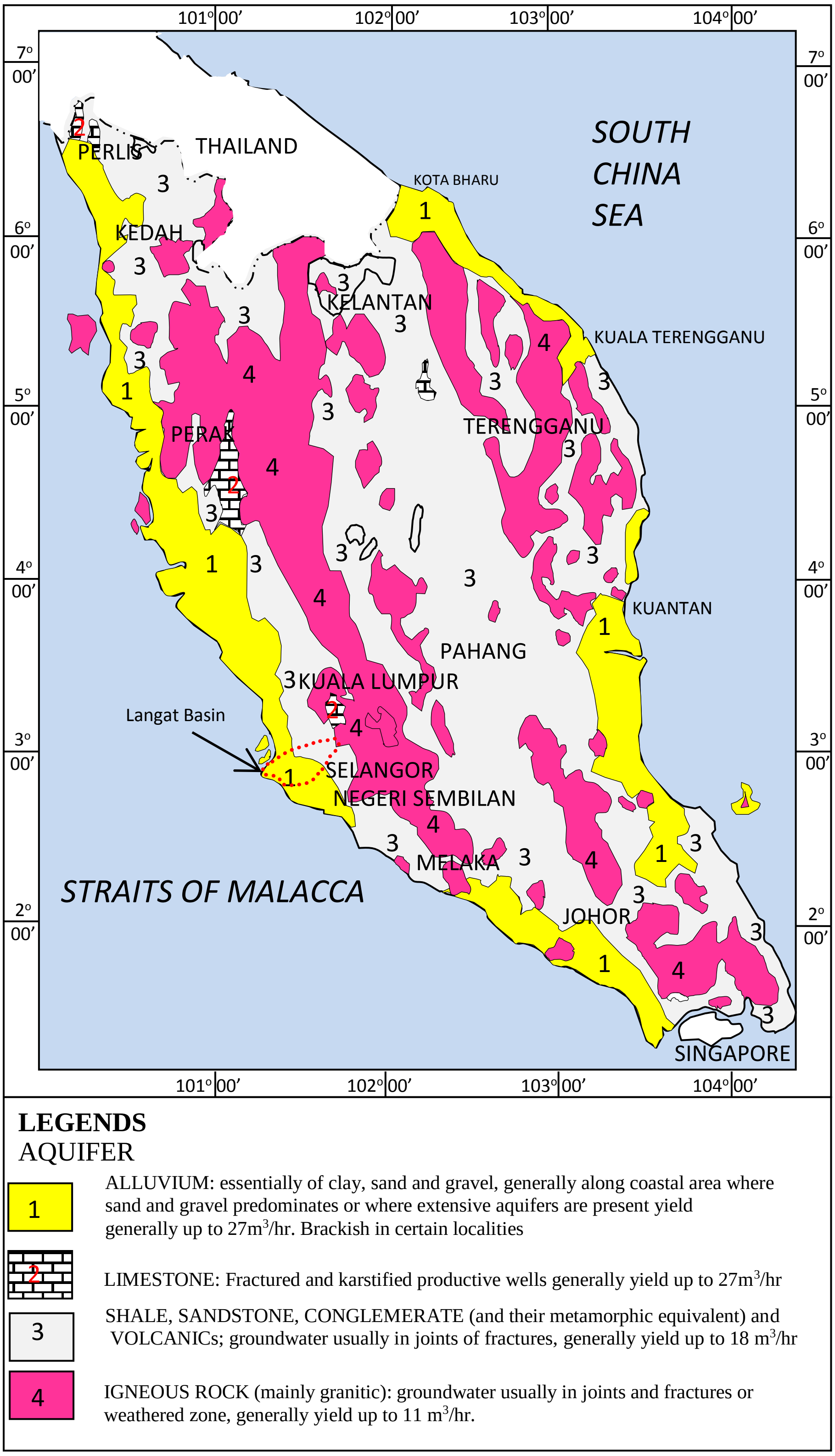


Figure 2.4: Groundwater map of Peninsula Malaysia (Simplified from hydrogeological map in Peninsular Malaysia (1:500,000) First edition in 1975 by Chong and Pfeiffer, Geological Survey of Malaysia)

2.3.2 Regional hydrogeology of Langat Basin

According to the hydrogeology condition in Langat Basin can be divided into five categories, as below:

1. Aquifer Bedrock
2. Terrestrial Pleistocene Sediments (Lower Sand Member, Simpang Formation);
3. Shallow Marine Sediments (Upper Clay Member, Kempadang Formation);
4. Marine Origin Sediments (Gula Formation); and
5. Young Holocene Fluviatile Sediments (Beruas Formation).

The categorization was based on regional geology and sequence stratigraphy in Langat Basin. Figure 2.5 and Table 2.1 show the regional geology map and sequence stratigraphy of Langat Basin. Bedrock in the upper catchment area in Langat Basin (mountainous area) consists of schist and phyllite of Howthornden Formation in Old Silurian and granitic rock of Permian (JICA and DMGM, 2002). The granitic rock is mainly found at the upper part of the catchment area of Langat Basin (Figure 2.5). Bedrock in the middle catchment area (hilly area) consists of phyllite, shale and quartzite of Kajang Formation and Kenny Hill Formation. Geology of the downstream in Langat Basin (lowlands area) consists of Quaternary deposits which generally exhibit unconsolidated gravel, sand, silt and clay. The study area located within the alluvium Quaternary deposit comprised mainly of clay and silt in an environment of marine deposit as shown in Figure 2.6.

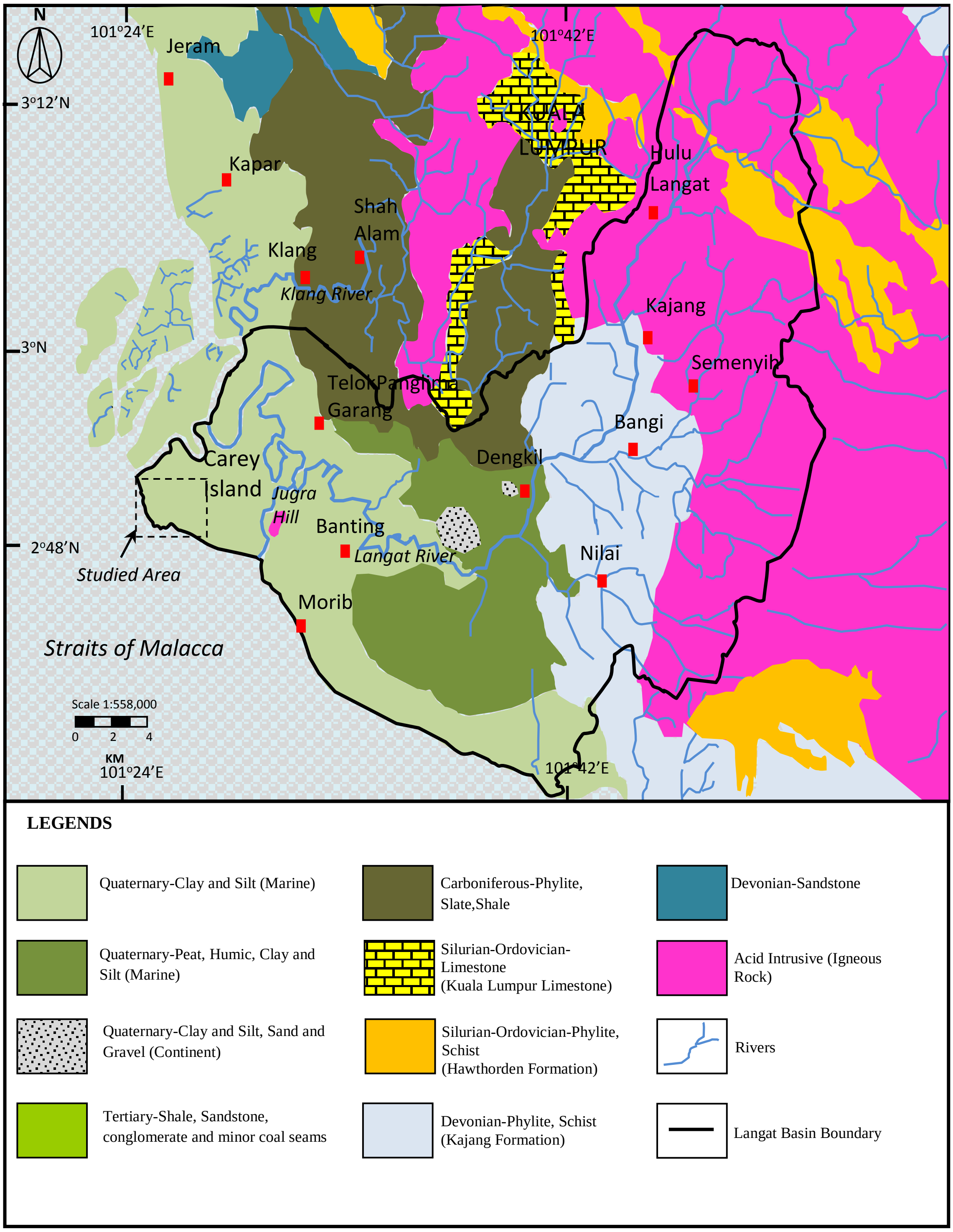


Figure 2.5: Regional geological map of Langat Basin

Table 2.1: Stratigraphy of Langat Basin's regional geology

Era	Formation	Member	Lithofacies
Holecene	Beruas Formation	Pengkalan Member	Inland freshwater deposits; clay, silt, sand
		Matang Timbul Member	Fluviatile, brackish lake deposits; silty clay
	Gula Formation	Port Weld Member	Mangrove, tidal flat deposits; silty clay
		Matang Gelugor Member	Sand ridge deposits sand
Pleistocene	Simpang Formation	Upper Clay Member (Kempadang Formation)	Shallow marine deposits; sand, gravel
		Lower Sand Member	Fluviatile deposits
Permian	Kenny Hill Formation	-	Shale, phyllite
Devonian	KL Limestone	-	Phyllite, schist
Old-Silurian	Howtherden Formation	-	Schist, quartzite

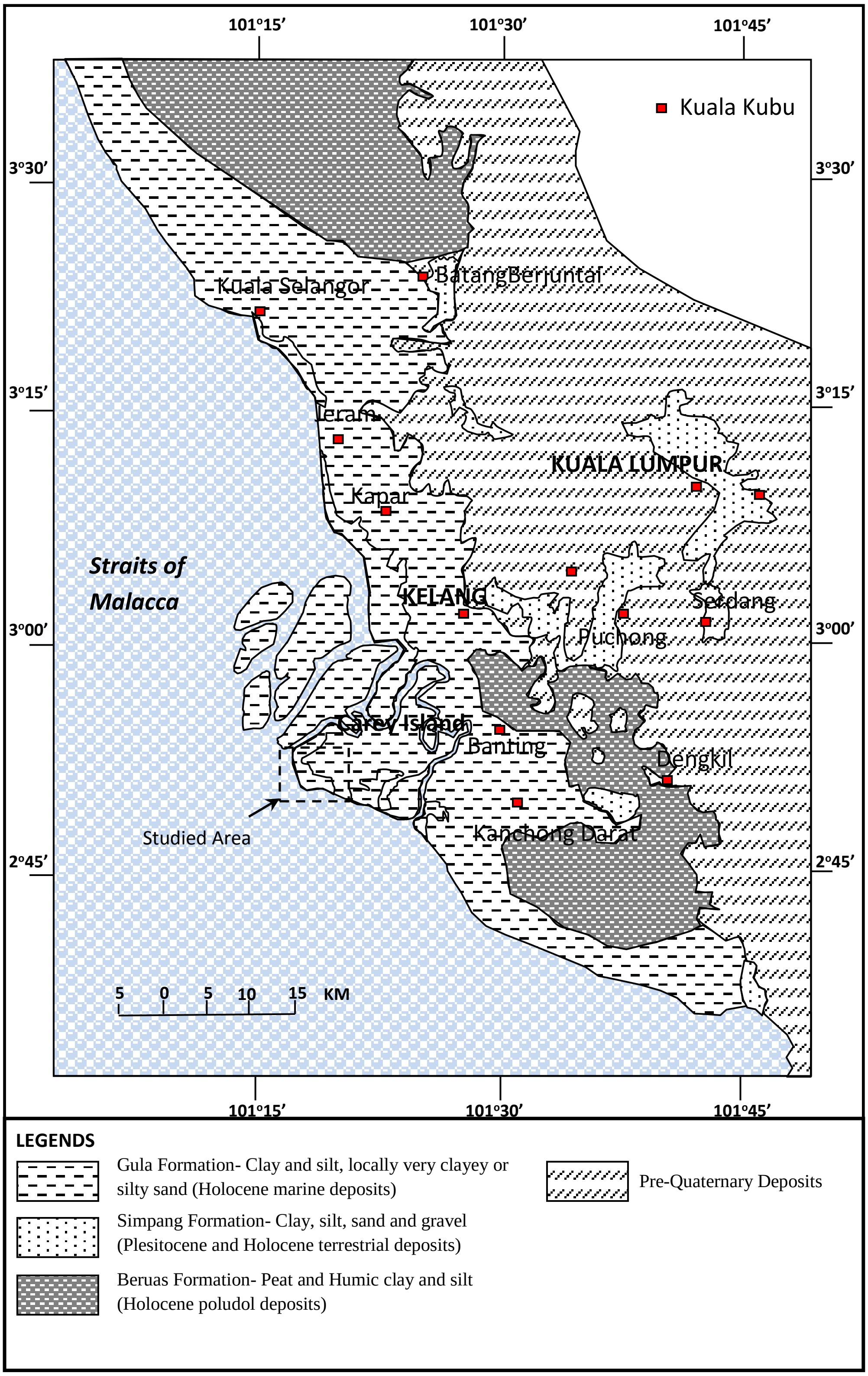


Figure 2.6: Geological formation overview of Langat Basin
(Modified from Bosch, 1988)

Pre-development of Quaternary sediments deposition in West Peninsular Malaysia started during Holocene sea-level changes. During the Holocene age, sea levels were more than 2 m above present level at some localities in Peninsular Malaysia (Sulaiman et al., 2003). The nearest location to the study area indicated, the sea-level change has reached about 5 m above the prior level during Holocene age before falling to its present position. The Holocene sea-level event affected the development of the coastal landforms. Low energy seawater wave and sheltered environments occurred in the west coastal area of Peninsular Malaysia encouraged the sedimentation process of fine soil material (Hassan, 2003).

The first studies of Quaternary deposits in Langat Basin were conducted by Suntharalingam and Teoh (1985) and Bosch (1988). Langat Basin's Quaternary deposits comprised of unconsolidated gravel, sand, silt and clay of Simpang, Gula and Beruas Formations. Only Gula Formation's and Beruas Formation's surfaces had been exposed. Simpang Formation can be identified from deep borehole logging. Meanwhile, Gula Formation is Holocene-age marine sediments existing over a large portion of the coast on Peninsular Malaysia's west side. The sediments comprised of gray clay and sand, minor gravel with traces of fragmented shells, and peaty materials.

Simpang Formation is characterized by clay, silt, sand, and gravel. The formation is terrestrial-sediment deposition of Pleistocene-age. The formation contains mainly of sand with fine to very coarse, and the sorting is from poor to well. Its gravel consists of quartz, chert, schist, feldspar patches, sandstone, and quartzite. The gravel is angular, sub-rounded, or rounded with the diameter ranging from 1 to 4 mm. The formation has formed the main aquifer in Langat Basin mainland. The presence of thick permeable materials (sand and gravel) shows its widespread distribution. The formation generally comprises of gravel grade layer at the lower part. The sediment compositions changed to sand grade at the upper layer. Quaternary sediments sequence showed higher permeability at the lower part and lower permeability at the upper part.

At the moment, the hydrogeological studies in Langat Basin for groundwater prospect are focussed in the alluvium Quaternary deposits. In the geology formation of mainland Langat Basin, groundwater aquifer can possibly be extracted in Simpang Formation. Existing production wells by Megasteel and Olak Lempit has been extracted from the Simpang Formation. The sand and gravel layer of Simpang Formation is the subject aquifer for the Management Plan by JICA and DMGM (2002) study. This aquifer distributes continuously around 15 to 20 m below the ground with the depths of 20 to more than 100 m. Thus it is generally assumed that groundwater can be developed economically in this area.

Chloride content in the groundwater samples collected from the monitoring wells of Langat Basin is presented as in Figure 2.7. The figure shows three categories of chloride content, a) more than 1,000 mg/L (saline), b) 250 to 1,000 mg/L (brackish), and c) less than 250 mg/L (freshwater). Figure 2.7 shows the saline groundwater 15 km from the shoreline. A line that divided the Basin by the standard, 250 mg/L (freshwater) standard of freshwater has been drawn along the southern bank of the Langat River.

Figure 2.8 shows the cross section of chloride content distribution of the groundwater basin. The chloride content ranges from 2,300 to 5,800 mg/L near the seacoast, and then decreases gradually towards the inland. At the boundary of the hilly area, the chloride content drops to below 10 mg/L. Contour lines of different groundwater salinity degree (saline, brackish and freshwater) in Figure 2.8 showed inclination trend of the Langat Basin mainland. Seawater intrusion from the Straits of Malacca is believed to have restricted regional fresh groundwater's extension to farther up the coast.

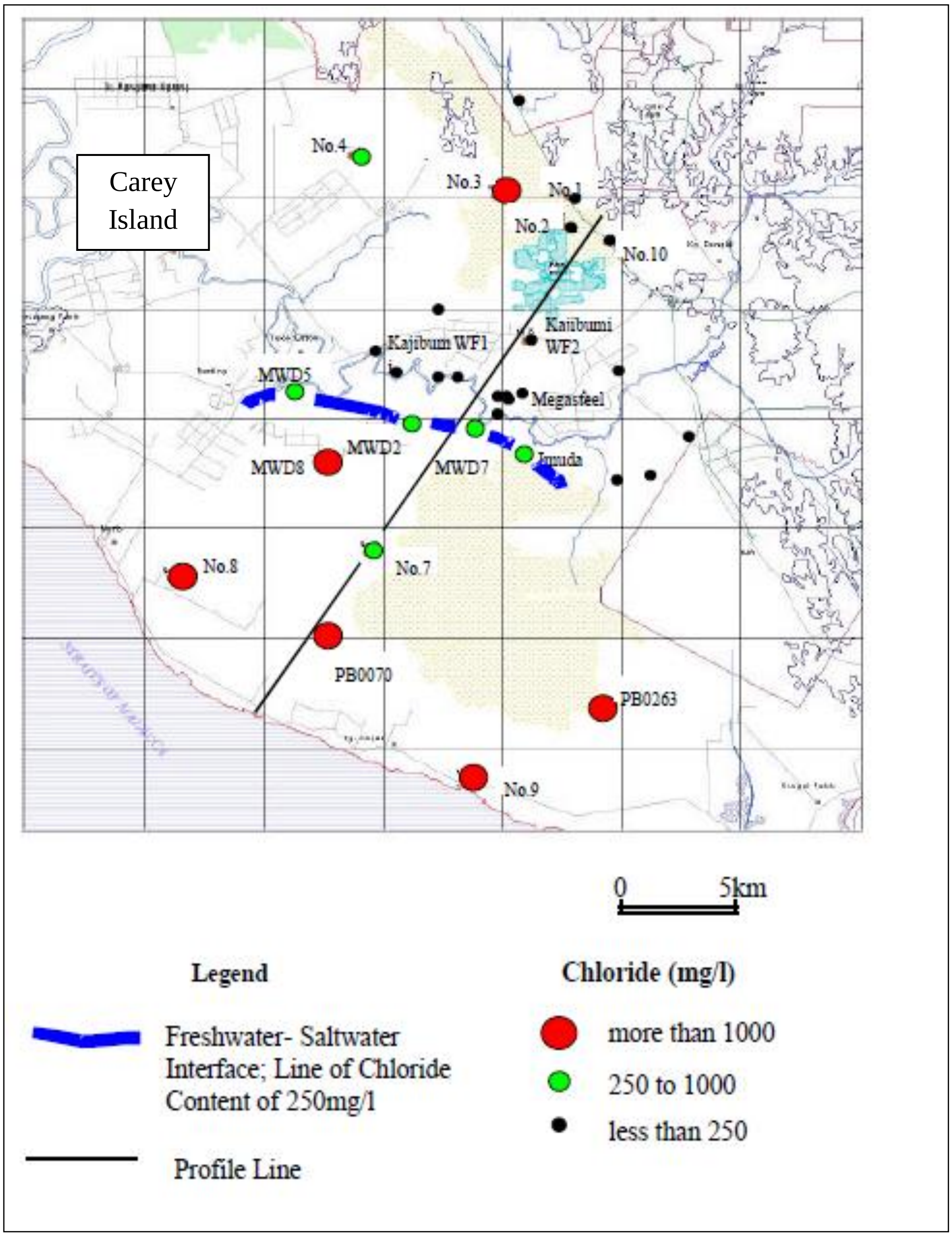


Figure 2.7: Saline and freshwater interface in Langat Basin mainland: 15 km from shoreline

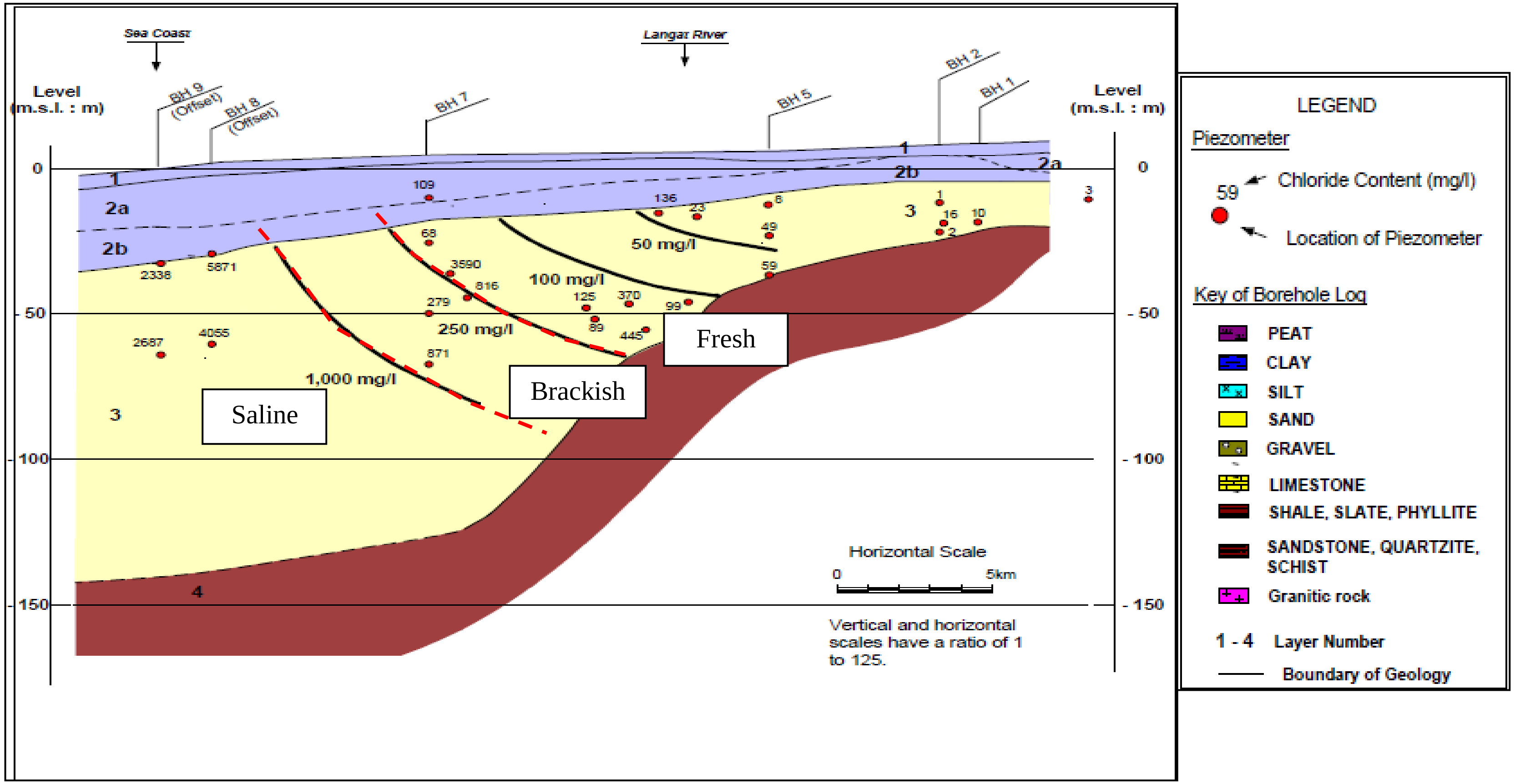


Figure 2.8: Distribution of chloride content within the aquifer. Saline and freshwater interface showed incline boundary

2.4 Agriculture activities in coastal area of Peninsular Malaysia

Malaysia has over 4,800 km of coastline across the Straits of Malacca, South China Sea, and Sulu Sea. The coastline of the Straits of Malacca and South China Sea is approximately 1,972 km, whereas that of Sabah and Sarawak crossing South China Sea until Sulu Sea is 2,837 km. The breakdown of the coastline of Peninsular Malaysia is 1,386 km for the west coast and 586 km for the east coast. Coastal areas contributed approximately 13% of the total land mass in Malaysia, with an area of 4.43 million ha.

The coastal zone of Malaysia with a long coastline and huge area, has a special socio-economic and environmental significance, which supporting 70% of Malaysia's population. In addition, the Malaysian coastal zone is also the center of economic activities encompassing urbanization, agriculture, fisheries, aquaculture, oil and gas exploitation, transportations and communication, and recreations. Among the coastal regions in Malaysia, the west coast of Peninsular Malaysia is the most developed socio-economically, with 57% of its coastline is utilized for agricultural activities and 21% for housing, transportation, and recreational facilities (Abdullah and Loi, 1992 and Syed Alwi, 1992).

2.4.1 Salinity effects on plant at coastal area

Salinity is a major environmental factor that causes reduction to plant growth and productivity in coastal area around the world (Croon, 1997). It was estimated more than 100 million ha of food producing areas in the world was affected by salinity. Approximately, 20% of the world's cultivated area and about half of the world's irrigated coastal lands were reported to be seriously affected by salinity and water logging (Munns and Tester, 2008, FAO, 2008). In general, high salinity causes reduction in the water absorption potential. It leads to the reduction of freshwater availability to plant. It causes difficulties for plant to obtain water and nutrients. As a consequent, rapid reduction in growth rate and productivity occurred (FAO, 1973, Munns, 2002; Ashraf and Harris, 2004). Eleven millions of coastal areas faced salinity problem in the South Asia region (Abrol et al., 1985 and Mohtadullah et al., 1993). The land becomes unsuitable for cultivation due to the increase in salinity levels of the soil and subsequently damaging the crops (Kularatne, 1997). The increasing level of salinity is caused by seawater intrusion into the agriculture irrigations. Crop production during dry seasons is limited due to serious saline irrigation water (United Nation, 1994).

In Malaysia, the coastal plains in certain places are unsuitable for plant growth due to salinity problem (Mohd Hashim, 2003). Several factors of salinity occurred in the coastal area of Malaysia where the most significant factor is seawater intrusion to low elevation coastal landform. Other factors that also influenced salinity problems are tidal inundation, groundwater seepage and over-drainage of adjacent area. Various studies showed plants such as oil palm, rice and turf grass had been affected by salinity problem in the coastal area in Malaysia (Rao, 1982, Kimi, 1991; Uddin et al., 2012). The plant most affected by salinity problem in coastal area of Malaysia is oil palm (Mohd Hashim, 2003).

The study on oil palm plantation in coastal area of Carey Island, Selangor was conducted by Abd Razak et al., (1995). The study area covered about 2,000 ha that has been developed for oil palm plantation. The conductivity values of soil ranges from 0.5 to 2.4 S/m before the remedy action on salinity in this area was carried out. Nevertheless, after irrigation improvement and sufficient agronomic inputs were conducted, the conductivity values were reduced to about 0.1 or less than 0.1 S/m. As a result of the remedy effort taken, the yield of fresh oil palm fruit bunches in the fifth year of harvest for different fields increased from 14 to

27 ton/ha/yr. However, some effect of salinity was still observed in Carey Island through differences in yield between different locations. Areas that are adjacent to the coastal bund remain relatively more saline through seepage of saline water compared to other distant sites.

Previous studies focused on salinity problem in order to define the suitability of agriculture towards salinity (Rao, 1982, Kimi, 1991, Abd Razak et al., 1995; Uddin et al., 2012). However, there was limited study on the effect of seawater intrusion into groundwater aquifer that relates to agriculture activities at the coastal area. Groundwater for agriculture used in coastal areas can be affected by sea level rise in the 21st century due to climatic change (IPCC, 2001). Climatic change is expected to worsen the existing environmental problems along the coastal areas. Future sea-level rise near coastal aquifers may lead to a change in the present hydrogeological boundary. Saline groundwater is thicker than before and more shifts to the landward coastal areas in the future (IPCC 2007; Vaeret et al., 2009). The problem might become very serious when the effects of sea-level rise were to combine with the huge amount of water requirements for agriculture. This phenomenon requires practical measures to detect the present status of seawater intrusion to groundwater system, especially in the coastal area which extensively involved with agricultural activities.

In Malaysia, one of the most important agriculture activities to generate income for the country is oil palm. Palm oil industry is one of the major contributors to the Malaysian economy. It is timely to investigate the saline groundwater status and its impact to oil palm plantation at the coastal area.

2.4.2 Overview of oil palm plantation of coastal area in Malaysia

Oil palm (*Elaeis guineensis Jacq.)* is the major source of oils and fats traded worldwide. It contributes to 56% of the total exports, followed by soybean oil at 15% (Malaysia Palm Oil Board (MPOB), 2013a). Southeast Asia is currently the leading region for oil palm production, with Malaysia being the second largest producer and exporter in the world after Indonesia (MPOB, 2013a; MPOB, 2013b). Palm oil industry supplies the primary sources of income in Malaysia. The industry provides job opportunities and livelihood for over half a million of Malaysian people. This number is estimated to increase to 702,000 people in 2020 (Omar et al., 2010). Palm oil industry contributed 8% (USD 16 million) of the nation's Gross Domestic Product in 2011 (Department of Statistic Malaysia, 2012). The total area planted with oil palm in Malaysia was approximately 4,900,000 ha in 2013. The income from oil palm industry provided a lucrative monthly income to small-scale farmers from MYR 1,200 to MYR 1,800 per ha. The lucrative income from palm oil production had encouraged the small-scale farmers, estate plantation, and the government to increase the area for oil palm plantation in Malaysia (Omar et al., 2010). The total area planted with oil palms in Malaysia increased by 3.5% to 4.85 million ha in 2012 compared to the 4.69 million ha in 2011. In Peninsular Malaysia, the total area planted with oil palms is approximately 2.52 million ha. The concentration of oil palm plantation in Peninsular is more focused in the West Peninsular Malaysia rather than in the Eastern part. The area planted with oil palms in the West Peninsular Malaysia is about 1.54 million ha compared to that in the East Peninsular Malaysia with 0.99 million ha (MPOB, 2013b).

In the Peninsular Malaysia, coastal plains with relatively fertile alluvial soils are found on the west coast. Alluvial soils are also present in some parts of the east coast. Based on the topography factor, areas with greater than 20° slopes are unsuitable for oil palm plantations. Hence, only 42% of the 33 million ha of land in Malaysia is suitable for agricultural activity for oil palm (Abd. Ghani et al., 2004) and most of these locations are in coastal areas.

2.4.3 Oil palm physiography and salinity tolerance

In general, the oil palm requires warm tropical climate and high rainfall. Hence, the cultivation of this plant is at present confined to low lying areas of the global humid equatorial regions. The apparent best mean temperature range is 24°C to 28°C. The ideal rainfall pattern is 2,000 to 3,500 mm/yr, evenly distributed throughout the year with a minimum of 100 mm/month (Fairhurst and Hardter, 2003). The oil palm has an adventitious root system with four orders; namely, primary, secondary, tertiary, and quaternary (Figure 2.9). The length of the primary roots system varies by approximately 3 to 6 m, whereas the second roots can penetrate below 1.5 m (Corley et al., 1976; Williams and Hsu, 1979). These primary and secondary roots can possibly reach the high groundwater table. The amount of available water held in soil (unsaturated zone) is very important for the tertiary and quaternary root systems that cannot extend deeper in the soil. The total length for all root systems is estimated to be approximately 9,000 km/ha at usual planting densities (Tinker, 1976). The root system plays an important role for extracting nutrients and water for the growth of an oil palm. In general, oil palm cultivation along the coastal area is exposed to salinity problem. Salinity tolerance is the most important factor in determining the impact of soil and groundwater salinity to plant growth at coastal areas.

Plant tolerance limit based on salinity was introduced to Peninsular Malaysia by Wong (1986) as listed in Table 2.2. The tolerance limit is considered as a limitation to crop growth, together with 13 other soil factors. The tolerance limits of crops commonly grown in Malaysia were proposed based on electrical conductivity (EC) of soil in the root zone. Another salinity tolerance limit was proposed by Mohd Hashim (2003) (Table 2.2). The EC of the soil in a mixture with water at a ratio of 1:5 at 25 °C was used to distinguish between degrees of salinity. The limit proposed for the different degrees of salinity on the basis of the EC of soil–water mixture is in the ratio of 1:5. These limits are almost the same as those used in the plant tolerance limit develop by Wong (1986). As the system was based on crop tolerance under Malaysian conditions, the limits proposed should be acceptable for broader use. The suitability of oil palm towards salinity at 0.5 m of soil depth was proposed by Abd. Ghani et al., (2004). Comparisons of the different degree of salinity, plant tolerance and oil palm tolerance for various electrical conductivity range conducted is indicated in Table 2.2.

The limit for the classification in Table 2.2 is very similar to that in the study conducted by Wong (1986) and Mohd. Hashim (2003). The soil salinity and oil palm tolerance suggested by Abd. Ghani et al., (2004) can be widely used under Malaysian condition whether for saturated or unsaturated water condition. The oil palm will not be able to tolerate salinity when the EC limit exceeds 0.4 S/m, eventually will be leading the plant to its death.

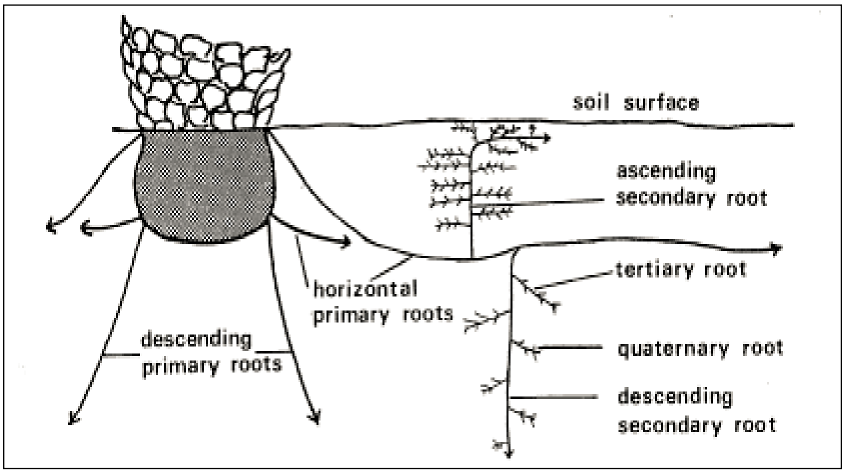


Figure 2.9: Diagram of the oil palm root system (Corley and Tinker, 2003)

Table 2.2: Different degree of salinity, plant tolerance and oil palm tolerance for various electrical conductivity ranges

EC value (S/m)	**Degree of salinity** Wong (1986)	**Plant tolerance** Mohd. Hashim (2003)	**Oil palm plant tolerance** Abd, Ghani et al., (2004)
> 0.4	Severely saline	very serious limitation	Not suitable
0.2 – 0.4	Moderately saline	serious limitation	Moderately suitable
< 0.2	Non-saline	moderate limitation	Suitable

Carey Island is one of the islands in Malaysia with major oil palm plantations that generate income of about RM 120 million per year (Berita Harian, 2011). A big part of the island is facing Straits of Malacca and has high potential of exposure to the seawater intrusion. Carey Island was chosen as the study area to determine the status of seawater intrusion into groundwater system. The assessment of current seawater intrusion to Carey Island would predict the limitation on the groundwater salinity towards oil palm plantation activity.

2.5 Overview of Carey Island

Carey Island is located on the west coast of Peninsular Malaysia (Figure 2.10). The island is separated from the mainland coast by the Klang River to the north and the Langat River to the east. Carey Island is the largest single island located at the mouth of the Langat River (Figure 2.10).

Carey Island is situated within the Langat Basin catchment area (JICA and DMGM, 2002). It is located at the eastern edge of Langat Basin (Figure 2.10). Furthermore, Langat Basin has crossed over two states; Selangor and Negeri Sembilan. The Langat Basin in Selangor includes the Kuala Langat District, the Sepang District, and the Hulu Langat District. In Negeri Sembilan, the Langat Basin is located at the western part of the Seremban District (Figure 2.10). The total size of the Langat Basin is approximately 2,750 $km^{2.}$ In the Langat Basin, Carey Island is situated in the Kuala Langat District. The island's total area, 162 km^2 represents approximately 6% of the total area of Langat Basin.

The island is an ex-promontory land. In the early 19th century, the island was connected to the mainland. The formation of the island is based on two theories. The first is that it had been part of a mainland that gradually disconnected due to the excavation made by the pirates in the nineteenth century. Second theory indicates that it had been promontory, and became an island when the Chinese broke through the little strip of land separating the river and the straits. Carey Island is in the coastal peat and alluvium zone of the west coast of Peninsular Malaysia. The whole island is flat and low lying with some part situated below sea level giving anecdote as 'undersea' tea or coffee as reported by Golden Hope Plantations Berhad, (2006). Jugra Hills with the height of 265 m from mean sea level is the highest point near Carey Island (Figure 2.10).

Edward Valentine Carey transformed the mangrove-preserved island into an agricultural area in the early twentieth century. Drainages were excavated to irrigate the area. Dykes, bunds, and tidal gates were constructed to control seawater intrusion.

2.5.1 Rainfall

The weather in Malaysia is characterized by two monsoon regimes, namely, the southwest monsoon from late May to September and the northeast monsoon from November to March. The northeast monsoon brings heavy rainfall, particularly to the east coast of Peninsular Malaysia and western Sarawak, whereas the southwest monsoon normally signifies relatively drier weather. The transition period in between the monsoons is known as the inter monsoon period.

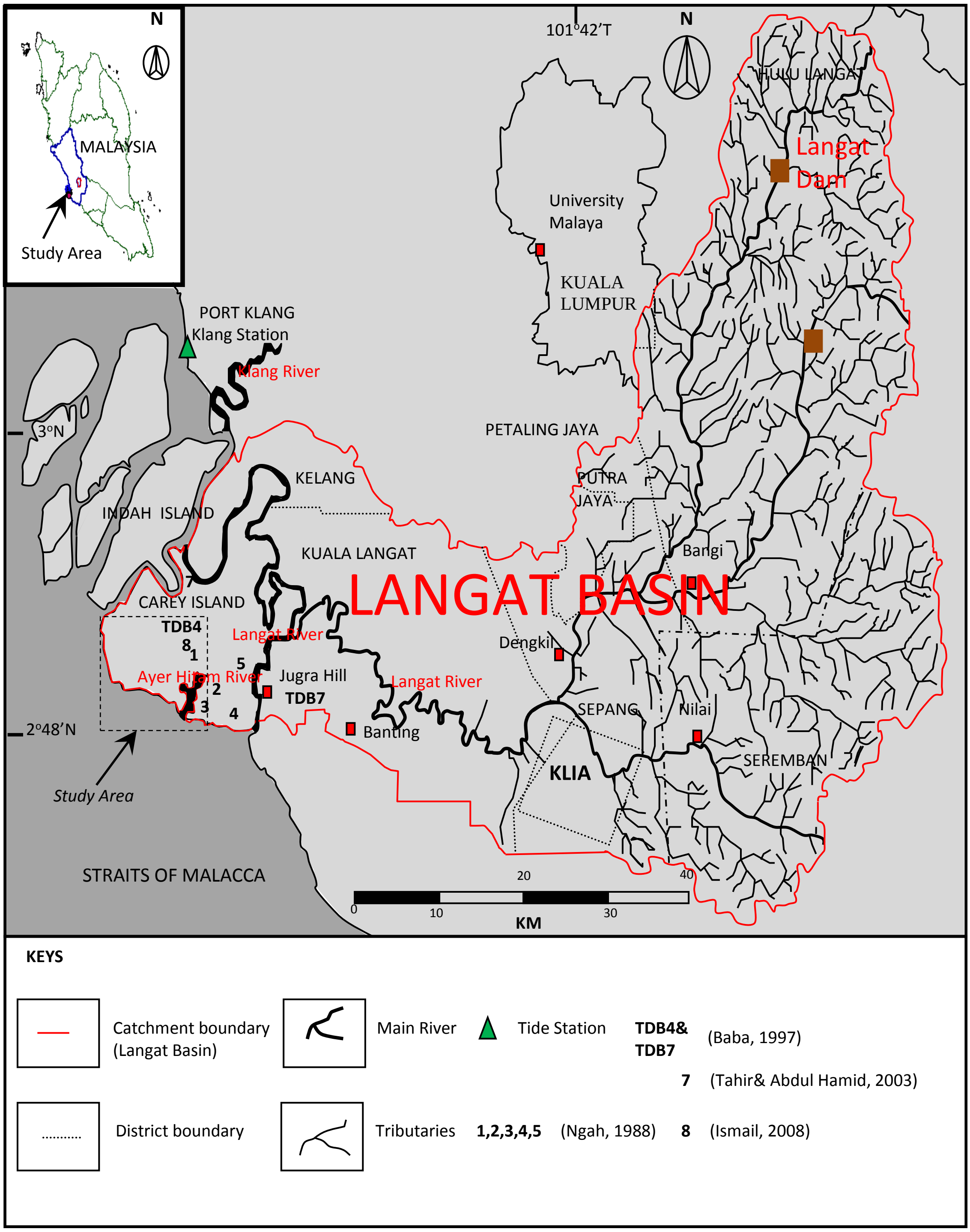
The following are the three main types of seasonal variation of rainfall in Peninsular Malaysia (M. Razi, 2014):

(a) November, December, and January are the months with maximum rainfall over the east coast districts, whereas June and July are the driest months in most districts.

(b) Over the rest of Malaysia, with the exception of the southwest coastal area, the monthly rainfall pattern shows two periods of maximum rainfall separated by two periods of minimum rainfall. The primary maximum rainfall generally occurs from October to November, and the secondary maximum generally occurs from April to May. Over the region, the primary minimum rainfall occurs from January to February, and the secondary minimum occurs from June to July. Over the remaining areas, the primary minimum occurs from June to July, and the secondary minimum occurs in February.

(c) The rainfall pattern over the southwest coastal area is much affected by "Sumatra's" rainfall from May to August, with the result of the double maxima and minima pattern is no longer apparent. October and November are the months with maximum rainfall and February is the month with minimum rainfall. The March-to-May maximum and the June-to-July minimum are absent or indistinct.

Carey Island is located at the southwest coastal area and the rainfall pattern falls into category (c). The maximum rainfall fall on the month of October and November and the minimum rainfall fall on the month of February.



Note: (Names of Villages: 1&7=Sg. Judah; 2=Sg. Rambai; 3=Kenanga; 4=KepauLaut; 5=Sg. Bumbun; 6=West Estate)

Figure 2.10: Location Map of Langat River Basin and Carey Island

2.5.2 Quaternary deposits and hydrogeology of Carey Island

The Quaternary deposit map shows Carey Island's located in Gula Formation (Figure 2.6). Baba (1997) comprehensively logged boreholes and mapped Quaternary deposit in the area. The studies revealed Carey Island's two underlying lithostratigraphy sequences of sediment alluvium Quaternary: Gula Formation, and Simpang Formation. It was reported that sand grain sizes in Gula Formation range from fine, to coarse, at TDB 4 (Carey Island) and TDB 7 (mainland) (Figures 2.11 and 2.12). As depth decreases, sand size decreases, sorting from poor to well. At Gula Formation's deepest layer, near Simpang Formation boundary, sub-angular and angular coarse sand and gravel are dominant. Depth of Gula Formation at Carey Island (TDB 4) is 54 m, and at mainland (TDB 7), 48 m.

Sequence stratigraphy below the 54 m depth in Carey Island (Figures 2.11 and 2.12) shows Simpang Formation underlying Gula Formation. It was reported that gravel at the boundary between Gula Formation and Simpang Formation had been caused by disturbance to fluvial-sediment deposit. Past studies on Quaternary deposits showed possible vertical increase with depth, of various unconsolidated grainy materials. Hypothetically, high hydraulic-conductivity at subsurface profile bottom contributions of geological formation, environmental deposition of materials, and sort materials.

Hydrogeological investigations from boreholes logging indicated that the type of aquifer is a semi-confined (Figures 2.10 and 2.11). Most of the well logging data especially in the island's east side indicated that the aquifer type is semi-confined. Deep-boring logging (TDB4 and TDB7) indicated the presence of marine clay at 30 m depth (Figure 2.12). Groundwater investigation at Sg. Judah indicated freshwater in the aquifers is less than 25 m deep. Thicknesses of the semi-confined aquifers ranged between 5 and 7 m (Figures 2.13 and 2.14).The freshwater here is found to be in the form of lens. Some shallow semi-confined aquifers here are identified as having brackish water with chloride concentration of 620 mg/L (Figure 2.14). In Bumbun area (Figure 2.15), high chloride content occurs at the depth exceeding 25 m. At Sg. Rambai and Kepau Laut, freshwater can be found in the shallow groundwater aquifer (less than 5 m) (Figure 2.16). Freshwater lens at semi-confined aquifer can be deteriorated by seawater intrusion, especially during dry season (Ngah, 1988). Stratigraphic connection between the mainland and the island shows possible hydrogeological connection.

Figure 2.11: Locations of the monitoring wells from previous study

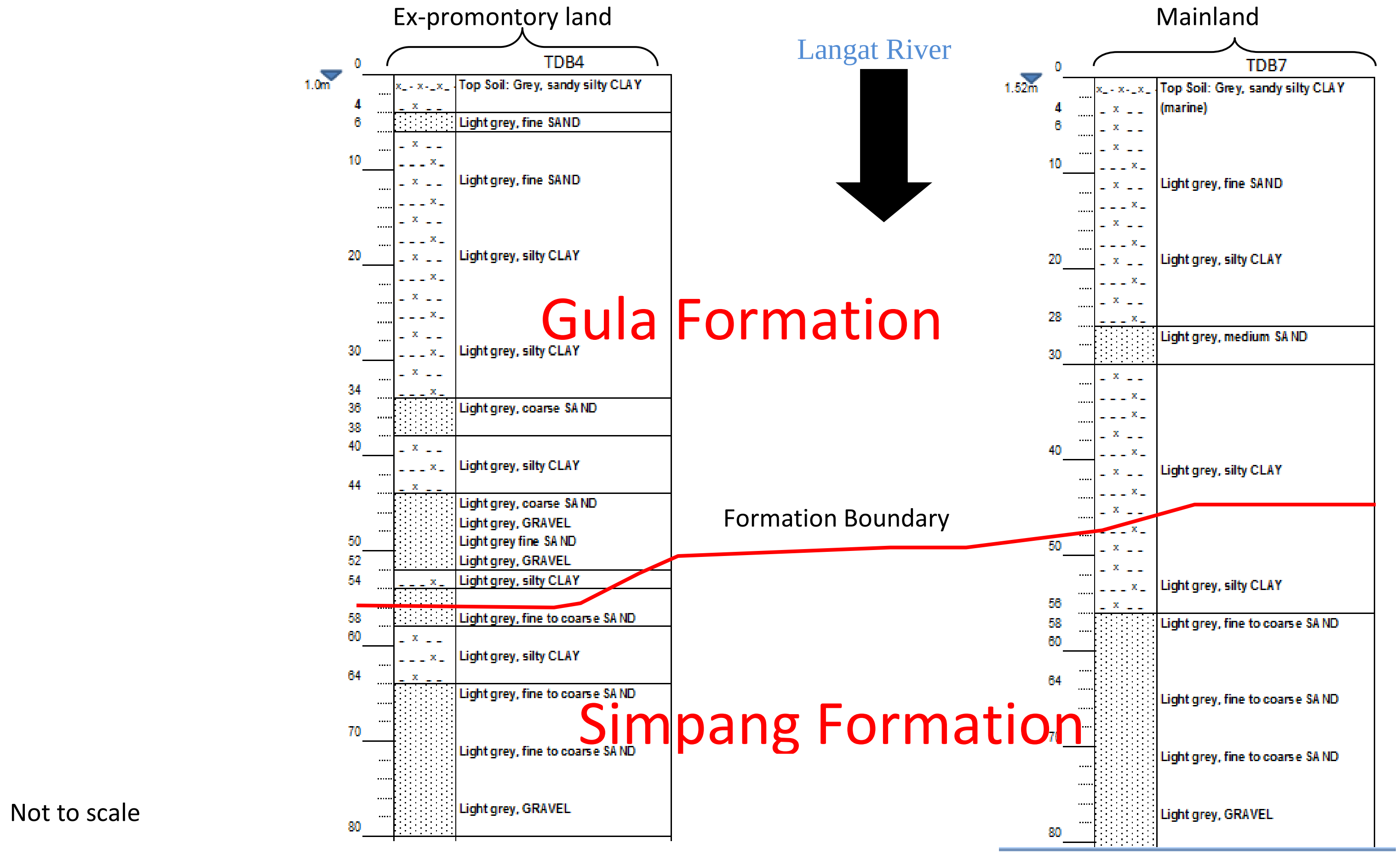


Figure 2.12: Depths of Gula Formation and Simpang Formation at the area studied.
Note depth of Gula Formation at Carey Island (TDB 4) is 54 m, and at mainland (TDB 7), 48 m (Baba, 1997)

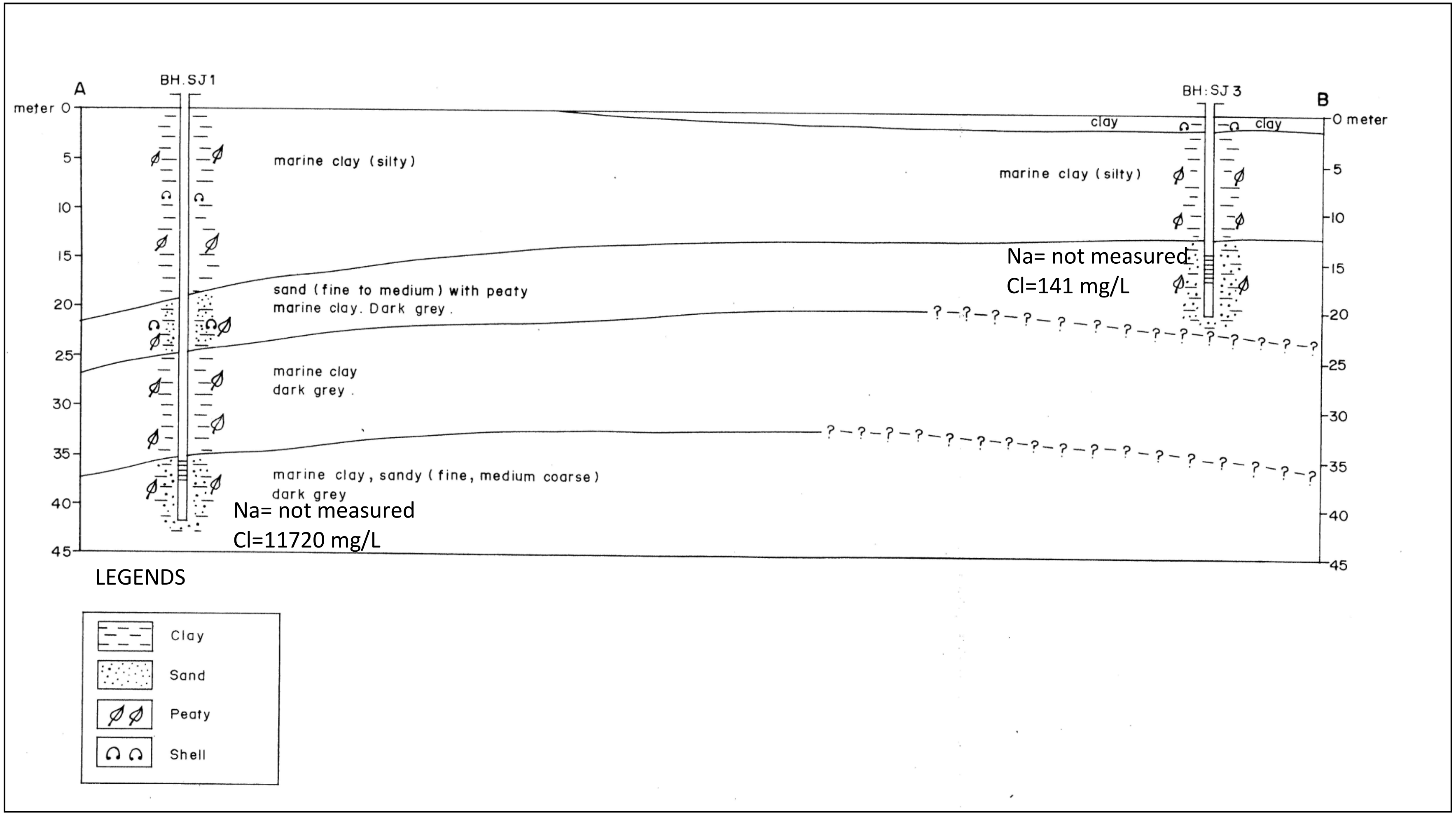


Figure 2.13: Sg. Judah village subsurface profile A-B and geochemistry data at semi-confined aquifer (Ngah, 1988)

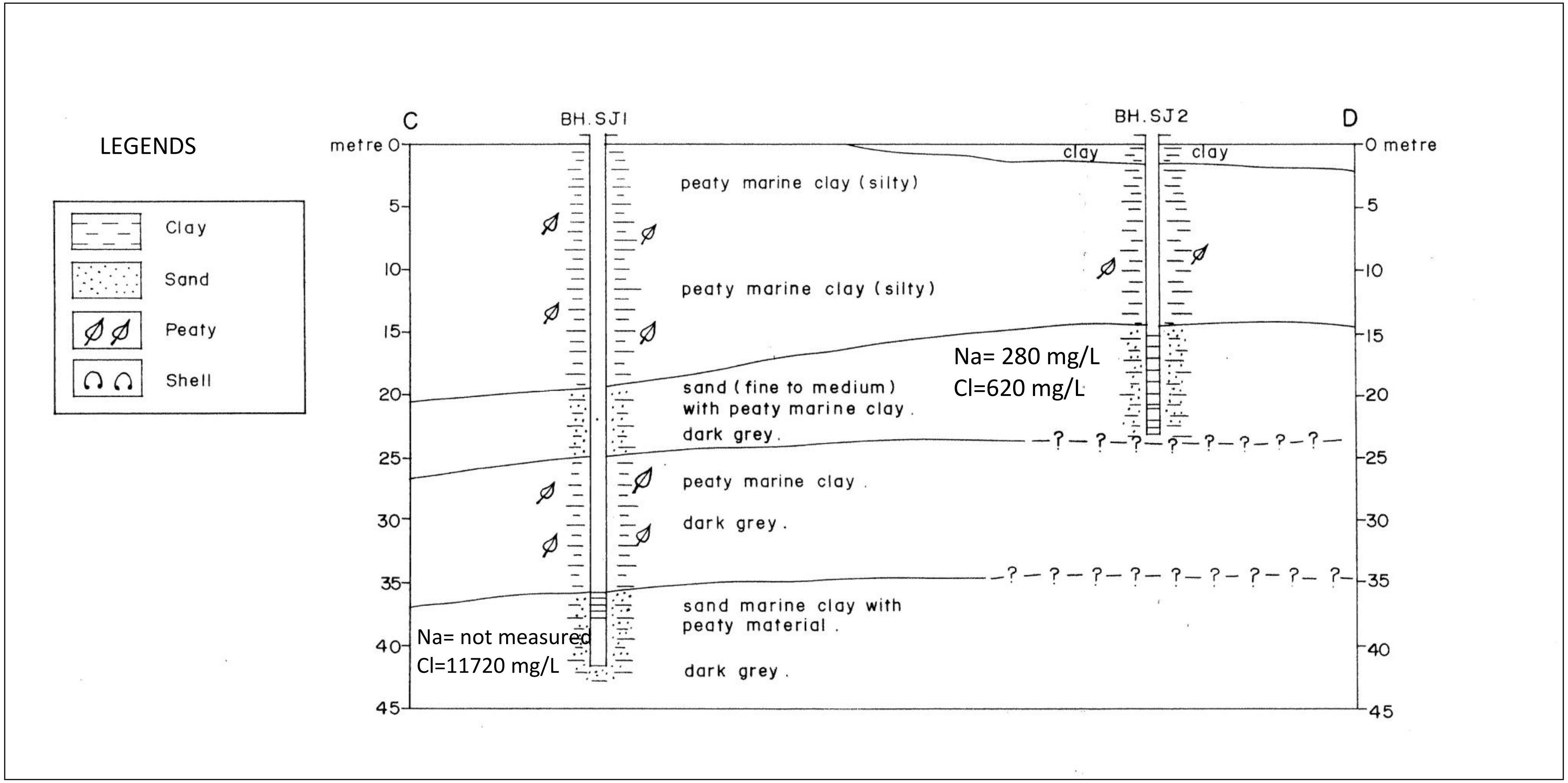


Figure 2.14: Sg. Judah village subsurface profile C-D and geochemistry data at semi-confined aquifer (Ngah,1988)

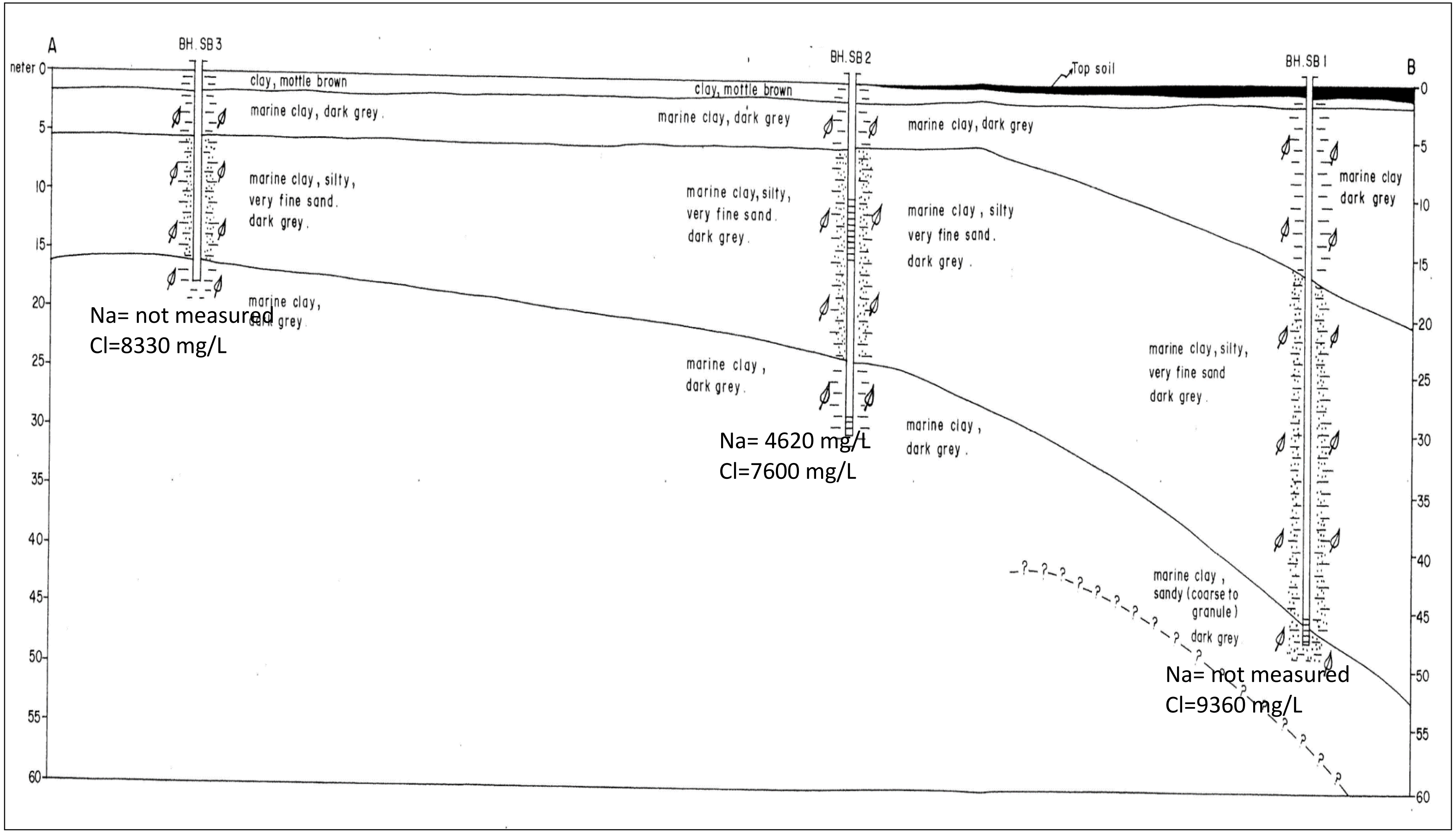


Figure 2.15: Sg. Bumbun village subsurface profile and geochemistry data at semi-confined aquifer (Ngah, 1988)

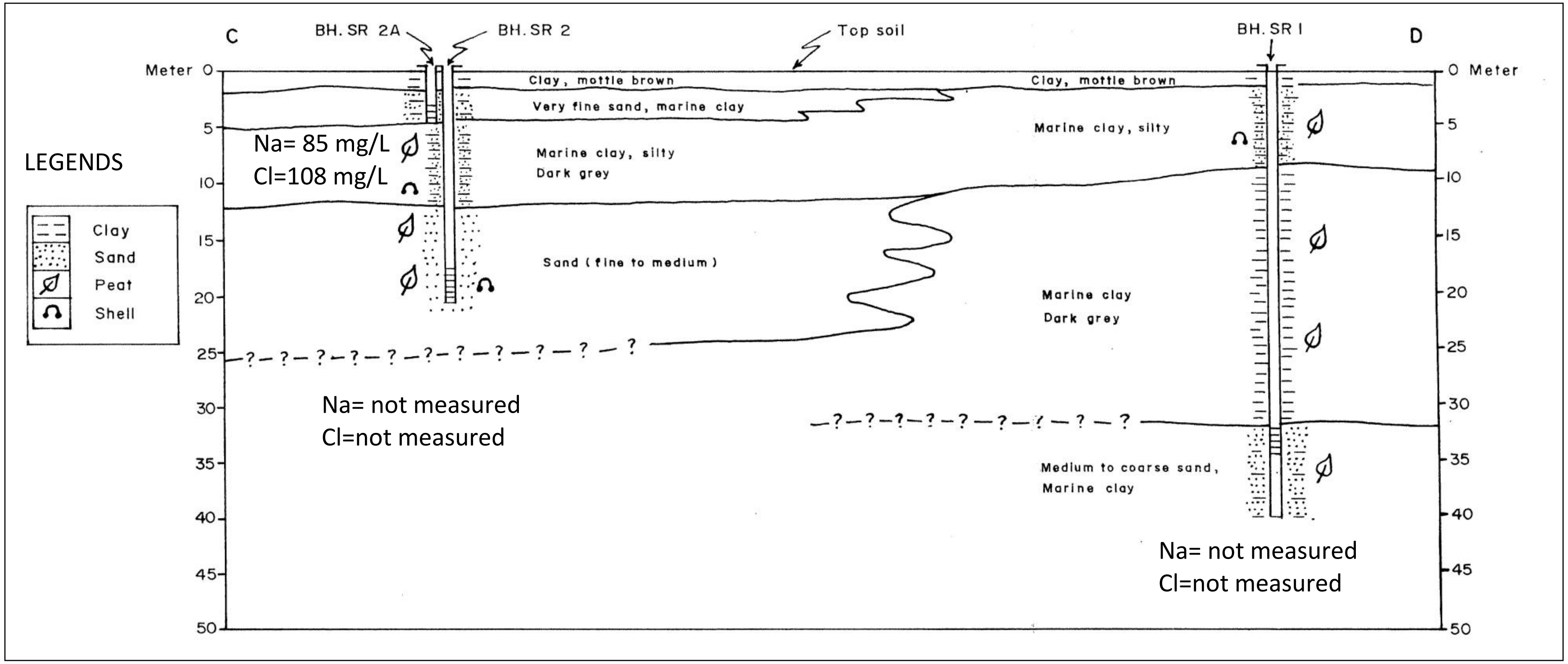


Figure 2.16**:** Sg. Rambai and KepauLaut village subsurface profile and geochemistry data at semi-confined aquifer (Ngah, 1988)

2.5.3 Socioeconomic activities

Carey Island's primary economic activity is associated with palm oil agricultural products. A total of 10,500 ha have been relegated to oil palm plantations, approximately 65% of the island's total area (Table 2.3). The island is unique in the sense that it is the only island in Malaysia which cultivates oil palms. The oil palm plantations cover 5,000 ha in the west and 4,100 ha in the east. However, the western plantations are productive on 75% of its total acreage; while the remaining acreage (25%) is unproductive (Berita Harian, 2011). The average fresh fruit bunch production of 40 t/ha for 2009 until 2010 constituted the country's highest yield under the 4,000 ha acreage category as recognized by Malaysian Palm Oil Board (MPOB). This production has led to an estimated total income of USD 120 million per year from the palm oil industry.

2.5.4 Carey Island's history of groundwater use and present water supply status

The history of groundwater usage in Carey Island is showed in Figure 2.17. The *Mah Meri* aborigines were believed to be the first-generation users of the groundwater. Senior citizens recalled their experience with the water supply between early 1950 and 1990, when Kokoh and Bangkong had mostly only shallow aquifer groundwater, drawn with hand-pumps by aboriginal villagers and estate workers. They described that water as mucky, especially in the dry season. Piped surface-water supply was commissioned only in the late 1990s; however, the supply was inadequate, so rain was harvested via culverts. This phenomenon can be observed in all residential houses in the estates in Carey Island.

Table 2.3: Summary of land use activities at Carey Island
(Golden Hope Plantations Berhad, 2006)

Land use of the island	**Area in hectares (ha)**
Area planted with oil palm	10,521.84
Forest Reserves (mainly mangrove)	1,876.85
Land parcel granted to the company	82.35
Concession held by Yayasan Selangor	1,583.61
State Land	1,340.72
Prawn Breeding concession	103.52
Area under Orang Asli Settlement	532.11
Area under other settlements, (Malay and India Villages	146.45
Total	16,187.45

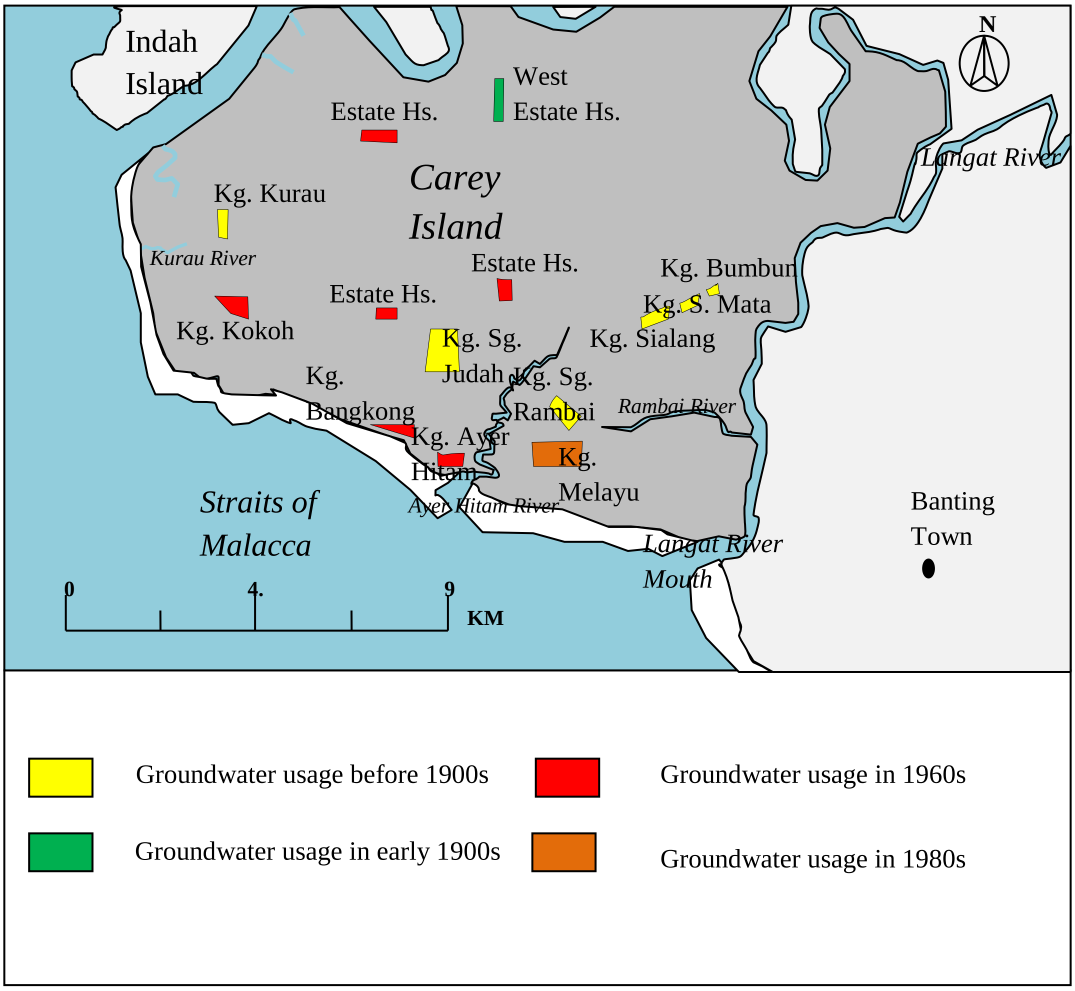


Figure 2.17: History of groundwater usage in Carey Island

The inadequacy was due to withdrawal of water supply by other users (industries, oil palm plantation, Putrajaya, and Kuala Lumpur International Airport) in the Langat Basin (Suratman, 2005) (Figure 2.10). Selangor's water shortage of 1,000 ML/d in 2007 was predicted by Tahir and Abdul Hamid (2003). The National Water Resources Study (GOM, 2000) predicted Langat Basin's water demand in 2012 to be approximately 1,200 ML/d but its present water supply is only 1,000 ML/d. Government agencies, such as the Department of Mineral and Geosciences Malaysia, were asked to conduct a study determining the area's water-supply potential. The investigation on the groundwater potential of shallow aquifers in five aboriginal villages was conducted by Ngah (1988) as showed in Figures 2.10 and 2.11. The study especially in Sg. Judah and Sg. Rambai revealed freshwater lenses in the aquifers were less than 25 m deep. No promising groundwater potential in the aquifers more than 30 m deep owing to the dominance of saline and brackish water (Figures 2.13, 2.14 and 2.15). It is also contributed by the isolated freshwater lenses in some areas in the semi-confined aquifer of the island. A continual investigation was conducted by Tahir and Abdul Hamid (2003), as requested by the Malaysian Government and as provisioned in the Eighth Malaysia Plan (2000 to 2005) for the north area. The investigation revealed that groundwater 95 m deep remained dominated by brackish water (chloride concentration more than 250 mg/L). Screen level at the depths of 175 m to 180 m was encountered in the study by Ismail (2008), indicating no potential for groundwater-extracted water supply given the dominance of brackish water (conductivity more than 2,000 μS/cm). The previous study was attempted to understand the area's hydrogeology for the planning of groundwater exploration strategies. The island's exploration and groundwater usage history yielded the conclusion that freshwater lenses potentially occur in shallow semi-confined aquifers.

2.5.5 Land use

Besides oil palm plantation, other land use activity of Carey Island is shown in Table 2.3. At present, the mangrove reserve forest is the second main activity in Carey Island. Distribution of the mangrove forest is concentrated along the coastal area, except for the southern area, which underwent extensive deforestation (Affandi et al., 2010). Prior to the early 1900s, the majority of Carey Island (especially in the coastal areas) had been a mangrove swamp. Carey Island was reported to be located in the thickest belt of the coastal swamp, most of which is sand, mud, and mangrove (Golden Hope Plantations Berhad, 2006). Edward Valentine Carey opened Carey Island in the early 1900s, cultivating rubber and then palm oil. Coconut was another hugely cultivated, which was the earliest plantations placed at the newly cleared land along the coastal belt. In areas where the tidal mangroves were retained, coconuts were planted immediately past the mangrove line. The jungle towards the island's center was reserved for rubber. By the 1920s, a total of 2,600 ha had been planted with coconut and 4,200 ha with rubber. As the rubber-planting trend was temporarily halted in the early 1920s, approximately 1,200 ha were planted with coconuts. Tea was another crop that changed the land use in the north and west, covering 470 ha of Carey Island. Since 1955 onwards, all the crops (tea, coconut, rubber) were replaced by oil palm.

The study area is focused on the northwest and southwest location of the island. The southwest area is the mangrove deforestation that has been confined to oil palm plantations. Mangrove stumps were found up to 300 m seaward of the present shoreline, indicating a large-scale of deforestation (Affandi et al., 2010). The mangrove deforestation was caused by frequent seawater waves from the southwest and west directions during the monsoon season. The site is exposed to direct wave action, which is very unfavorable for mangrove establishment. This observation is consistent with the reports by Tjia et al., (1973). However, mangrove deforestation was also attributed to the low of mangrove biomass (Affandi et al., 2010).

Based on the description in the paragraph above, the entire island (16,200 ha) had mangrove covered (before 1900) less than the present mangrove forest reserve (1,900 ha). A mangrove loss of 88% was estimated as a result of land opening and sea-wave devastation, which is interpreted as loss of barrier to seawater intrusion. This situation could well be more acute in the south but very much less in the west where some 1,800 ha of mangroves are still intact to this day. Therefore, there is a need to investigate the effect of seawater intrusion on the groundwater aquifer for the consideration of future domestic water supply and oil palm water requirements.

2.6 Summary

Previous studies focused on soil salinity problem in order to define suitability of agriculture related to saline environment. However, there was limited study on the effect of seawater intrusion into groundwater aquifer with relation to the agriculture activities at coastal areas. Integration of geo-electrical and geochemistry methods is the best approach for the assessment of seawater intrusion into groundwater aquifer. The study done by previous researchers used the geo-electrical and geochemical methods but the data obtained from the two methods were not integrated to produce a correlation between the data. There was also some misinterpretation of the resistivity value with the groundwater salinity degree. Alluvial coastal which consists of clay layer should not be included to classify the relationship between resistivity value and groundwater salinity degree. Therefore, the determination of the subsurface hydrogeological strata is essential to be firstly conducted before the integration method can be used.

The type of aquifer in Carey Island is a semi-confined. The aquifer covers about three quarters of the island from the east until it reached some parts of the west area. However, other studies have yet to explain the hydrogeological characteristics of the west and south area which are exposed to seawater. This study is to obtain new subsurface geological information by conducting site investigations at the west and south areas. This study is also important for obtaining new information of the hydrogeological characteristics and groundwater conditions that facing seawater directly.