

Chapter 20

Spatial and Temporal Patterns of Groundwater Quality in Selangor, Malaysia

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Abstract The groundwater quality varies in short periods affected by the natural and anthropogenic factors. This study examines the spatial and temporal variations of groundwater quality at Selangor, Malaysia aimed to determine the availability of groundwater resources. Providing information and data for a holistic and comprehensive management, sustainable development of groundwater can be implemented based on the quantity and quality monitoring. The temporal variations of these major water quality data were cross-checked against the hydrologic variations. The mapping and graph of water parameters were plotted and analysed using geographic information system (GIS). Analysis was based on a short-term data collected from three prominent groundwater wells supplying raw water. A total of 22 water parameters were used for quality analysis and then compared to the previous results conducted by Japan International Cooperation Agency (JICA) in 2002. Results showed that the availability of groundwater in Selangor State quantity was adequate and the quality meets the requirement standard. Considering the fact that groundwater is part of the hydrologic cycle, proper water management procedures, planning and policies can be achieved only through an integrated approach involving both surface water and groundwater.

1 Introduction

Groundwater is water that is found beneath the ground surface in soil, sand and rocks spaces and in fractures of rock formations. The depth at which soil pore spaces or cracks and voids in rocks become completely saturated with water is

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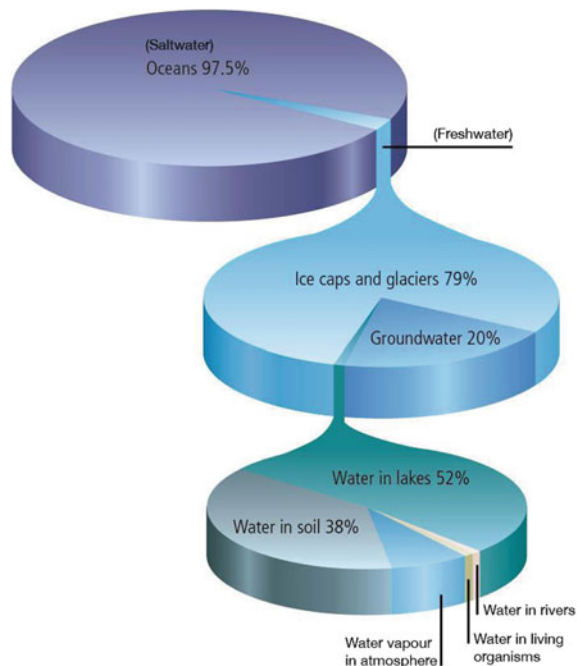
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called water table (Ramakrishnalah et al. 2009). Groundwater can be found almost everywhere and the water table may be as deep as tenth of metres and as shallow as one metre. It can be brought to the surface naturally through a spring or extracted through a well drilled into the aquifer. In rural areas, groundwater is taken out through shallow dug wells or comparatively deep tube well. While in urban areas, groundwater is pumped to the surface.

Generally, the term groundwater would be defined as water that is found underground the Earth surface. Hydrologists use the term groundwater to highlight water in the zone of saturation in which the entire void of space is filled with water (Heath 1983). However, Sato and Iwase (2006) have defined groundwater as all water below ground. Groundwater is water that is found underground in cracks and spaces in soil, sand and rocks and can be found almost everywhere. Groundwater occurs in two different zones which are as follows: saturated zone where all interconnected openings are full with water and the second zone is unsaturated zone where it occurs immediately below the land surface and contains water and air.

The area where groundwater fills these spaces is called the saturated zone of a geologic formation. The top of this zone is called the water table which may be only a metre below the ground’s surface or it may be hundreds of metres down. Groundwater is stored and moves slowly through aquifers or sometimes known as the reservoirs of porous media such as sand, gravel and limestone, thus the speed at which groundwater flows depends on the size of the aquifers and the connection of the spaces. Groundwater is brought to the surface naturally through a spring or can

Fig. 1 Water distribution.
 Source World Water
 Distribution Year (2010)



be discharged into lakes and streams. This water can also be extracted through a well drilled into the aquifer, refer Fig. 1.

For the fact that supply of clean water is a major component of survival, solely dependency on the surface water sources needs to be diverted. Moreover, surface water resource supply is getting affected due to various factors such as deteriorated water quality, exposure to pollution and increasing water demand (Horton 1965). Therefore, a detailed study on groundwater resources is very much essential to ensure raw water reserves of Selangor State is enough to meet the quantity and quality water supply (Rahim et al. 2009).

Major threats to groundwater quality may come from point source which is urbanization industrial wastewaters for instance, septic tanks, sewer and detergents. Other than that, non-point (diffuse) sources might also be a threat to groundwater quality. Agricultural chemical such as fertilizers and pesticides are an example of non-point sources. If the groundwater is polluted, it can move from the original source of contamination over a wide area or even a very deep underground. It is usually difficult to know where the contamination has gone (Ramachandra 2006). The risks to health will depend on the concentration and type of contaminants in the groundwater and also for how long, how often and in what ways people are exposed to the water directly by drinking and inhalation or indirectly through skin contact.

As case study, this research examined the spatial and temporal variations of groundwater quality at Selangor, Malaysia aimed to determine the availability of groundwater resources. The Availability of Groundwater Resources Studies of Selangor States in year 2008 is referred for proposed water resources development by using the groundwater resources, particularly during the water crisis period in the future. It is consistent with the proposed groundwater resources development as a new water supply sources to supplement 30% amount to the State of Selangor in 2030 (Lin et al. 2008).

1.1 Groundwater Recharge and Discharge

Groundwater recharge and discharge define the relationship among groundwater storage, precipitation, vapour transpiration and surface water. Thus, groundwater recharge and discharge are the hydrologic processes by which water is exchanged between the saturated zone, unsaturated zone, land surface and atmosphere.

Recharge can be determined as a process by which groundwater is replenished. From the groundwater section view, recharge area is where water from precipitation is transmitted downward to an aquifer. Nearly, all areas, except composed of solid rock or covered by development, allow a certain percentage of total precipitation to reach the water table. But in several areas, more precipitation will infiltrate than in others. Areas which transmit the most precipitation are regularly referred to as critical recharge areas. Natural vegetation cover, flat topography, permeable soil, a deep water table and the absence of confining beds act as a promoter or factor for recharge process. Therefore, how water infiltrates depends on these factors.

Discharge areas are the antonym of recharge areas. They are the locations at which groundwater leaves the aquifer and flows to the surface and normally occurs where the water table intersects the land surface. When this happens, springs or seeps are found and may flow into freshwater bodies, such as lakes or streams, or they may flow into saltwater bodies.

By referring to the force of gravity, groundwater commonly flows from high areas to low areas. So, high areas such as hills are naturally where aquifers are recharged and low areas such as river valleys are where they discharge. Nevertheless, in many instances, aquifers occur under the river valleys, thus river valleys can also be important recharge areas (Yusoff et al. 2013).

1.2 Groundwater Development in Malaysia

Malaysia water demand is likely to grow significantly by approximately 17,000 million litres per day (MLD) when the country's population reaches more than 30 million according to 2009 press released by Sime Darby (Bahagian Hidrologi dan Sumber Air 2009). At present, surface water accounts for more than 98% of water consumed in Malaysia. This level of dependence is unsustainable and needs immediately to be addressed, especially since surface water is easily exaggerated by extreme weather conditions, as Malaysians know only too well. This is a matter of serious concern for the whole country and all responsible organizations should be looking into addressing this imbalance in our national water supply. Groundwater offers a more consistent and sustainable source of water as long as it is abstracted properly, utilizing right methods and technology (Mohamed et al. 2009).

For the records, groundwater in Malaysia stores for more than 90% of the freshwater resources. The whole water available for use could be approximated as the sum of 10% of the surface run-off and the volume of groundwater recharge. But, not all groundwater can be abstracted as some of these aquifers fall on developed land or land where detailed groundwater assessment is difficult. Several aquifers may not be suitable for further development, as the water quality may be poor and difficult to treat while others are already intruded by saline water.

Even though water supply for domestic, agricultural and industrial use in the country is drawn primarily from surface water sources such as rivers and streams, groundwater has also played an important role in supplying the needs in several places, particularly in rural areas and in areas where piped water supply is inadequate or non-existent. Rural populations rely on groundwater obtained from wells for their daily needs and activities such as drinking and irrigation. Groundwater is also being used by various factories, estates and farms to suit their individual water needs including the commercial production of mineral water. During the dry spell, groundwater has provided relief for people in Selangor and Sarawak. Groundwater is certainly capable of supplementing water requirements for the country as a few states had utilized the groundwater resources for public water supply like in

Table 1 Water resource summary in Malaysia (Minerals & Geoscience Department Malaysia)

Water resources	Quantity (billion m ³)
Annual rainfall	990
Surface run-off	566
Evapotranspiration	360
Groundwater recharge	120
Surface artificial storage	25
Groundwater storage	5000

Kelantan, Perlis, Pahang, Sabah and Terengganu. Table 1 shows the summary of water resources in Malaysia.

1.3 Groundwater Supply in Selangor, Malaysia

Selangor is very well-developed state and public water supply services provide potable water to almost 95% of populated areas. As such, groundwater is mainly used for non-portable purposes. Selangor Water Management Authority (LUAS) started the groundwater registration programme in 2005 whereby groundwater abstractors are required to obtain a license and submit details of the abstraction method and volume abstracted (Suratman 2005). Groundwater in Selangor occurs in both alluvial and hard-rock aquifers. The groundwater output recorded for 8 years duration from year 2005 to 2013 indicates a rapid rise (80%) in groundwater abstraction from 1.8 million cubic metres in year 2005 to 21.6 million cubic metres in year 2009 mostly to meet the industrial demand (source: LUAS).

The exploitation of groundwater for both irrigation and portable use is not common due to abundance of surface water in Malaysia's river system. Except in the state of Kelantan and some parts of Sabah and Sarawak where portable water supply is extracted from groundwater aquifers (Hossain 1989). Most of the industrial and domestic water supplies as well as the irrigation water supply in the country come directly from the rivers. The National Water Resource Study (NWRS) for Peninsular Malaysia (2000–2050) has recognized the groundwater resource is an important supplementary resource for those isolated rural areas not served by the water supply networks.

Groundwater is also the main source for agricultural irrigation activities. It is a major contributor that flows in streams and rivers and has a strong influence on surface water and wetland habitats for fauna and flora. Based on the number of licences issued by Selangor Water Management Authority (LUAS), there were premises in Selangor which used groundwater as their water supply, such as factories, hydroponics, fish farming, and landscaping to ensure the cooling of industrial plants for domestic supply.

In study conducted by JICA in 2002 was to formulate a sustainable groundwater resources and environmental management plan for the Langat Basin using Geographic Information System (GIS). GIS is utilized in this study in input and

managing basic topographic maps, land use maps and other relevant data such as wetland, mining, forest reserves and so on (Manap et al. 2013). From the topography, the Langat Basin can be broadly divided into three, namely mountainous areas, hilly areas and flat lowlands, from the upstream to the downstream (JICA 2002). In the low flatlands, thick quaternary layers are deposited on the bedrock. The aquifer of the present study is the Simpang Formation consist sand and gravel. This aquifer distributes continuously around 15–20 m below the ground with the thickness of 20 to more than 100 m. It is generally considered that groundwater can be developed economically in this area. The average annual rainfall ranges from approximately 2200 to 2700 mm. The groundwater recharge is 108 mm a year which is 4.8% of the annual rainfall (Aller et al. 1987).

Groundwater quality for the highly acidic surface water significantly reduces the pH values of the groundwater to the range of 4.5–4.7. Total iron mostly exceeds the iron values specified in the Malaysian National Drinking Water Guidelines (0.3 mg/l). The higher concentration of arsenic values found in the shallower wells. Na_2SO_4 or NaCl type and intermediate type of water are dominant for the groundwater in this basin. The main activity of agriculture is dominated by palm oil plantation, followed by rubber, piggery, poultry, aquaculture, cattle and orchards. There are many types of pesticides being used mainly to control weeds, insects, rats and other pests. These pesticides and the fertilizer used in the palm oil are the potential source of groundwater pollution. Other potential sources include mines, solid waste landfill site, wastewater treatment plants and petroleum storage tanks of the petrol station (JICA 2002).

Land subsidence was the elevations of 20 shallow benchmarks that were measured in July and November 2000, and March and August 2001 to monitor the land subsidence. Three benchmarks were located near the Langat River indicate that have sunk around 11–16 mm since July 2000. These benchmarks are located in the area where much groundwater is extracted. The study concludes that consolidation by draining of peat/peat clay layer and clayey soil layer that are widely spread over the Basin may result in the subsidence around the area. Groundwater modelling was done to estimate the groundwater resources potential and also to predict groundwater abstraction impacts on the environment. The groundwater modelling software used was MODFLOW, MODPATH, Zone Budget, MT3D/RT3D and PEST. The geological layer was divided into seven layers for modelling purpose (JICA 2002).

In 2005, a study for sustainability on groundwater resources and environmental management for the Langat Basin was conducted by Suratman (2005). The geology of the study area is made up of Quaternary alluvium emplaced on top of sandstone and shale of the Kenny Hill Formation bedrock and Kajang Formation at the eastern fringe. Four units of Quaternary alluvium are recognized, namely the Beruas Formation, Gula Formation, Kempadang Formation and Simpang Formation. The groundwater recharge takes place mainly from upstream mountain and hilly areas. The groundwater can be classified as Na_2SO_4 or NaCl type. The chloride water indicates the influence of the seawater and marine origin sediments. Arsenic is widely detected although almost all are below the drinking standard of 0.05 mg/l and the highest concentration of arsenic is found in shallower wells. The potential

sources of groundwater pollution are from a total of 30 industrial estates in the Basin, agricultural activities dominated by palm oil and rubber plantation, mines, solid waste landfill site, wastewater treatment plants and petroleum storage tanks. The results of groundwater flow model developed using Visual MODFLOW indicate that groundwater abstraction from the main aquifer will cause only negligible drawdown in the wetlands and shallow peat layer. The shallow layer is affected more by lowering of surface recharge through rainfall.

1.4 Aquifers Conditions in Klang Valley

The two most important aquifers in the Klang Valley are the Kuala Lumpur Limestone and Kenny Hill Formation (Binnie and Rakan 1979). A third aquifer comprising river and coastal alluvium could be developed as a low yield groundwater source. The coastal alluvial aquifer shows high sodium and chloride contents as results of saline intrusion, the river alluvial aquifer has high contents of nitrates, sulphate and coliform counts, whereas the limestone aquifers show high nitrates and coliform counts (Peng 2012). Data collected from wells tapping the different aquifer types in the Klang Valley have been summarized and shown in Table 2 (Suratman 1990).

1.5 Klang Valley River System

Selangor State lies approximately between 312,017–44,3151 m Easting and 285,818–430,281 m Northing. The map of study area is shown in Fig. 2. There are

Table 2 Well hydraulics of aquifer in Klang Valley (Hydrogeology of Klang Valley 1990)

Aquifer		Alluvium		Kenny Hill	Kuala	Schist
		River	Coastal	Formation	Lumpur	
					Limestone	
Discharge (m ³ /d)	Min	327	46.4	78.45	108	108
	Max		193.32	1308.00	1113.60	360
	Ave		148.88	499.25	580.75	201.13
Transmissivity (m ² /d)	Min	242.1	9.86	1.66	1.22	6.09
	Max		84.66	671.33	1189.49	95.56
	Ave		52.1	40.83	198.29	53.27
Storativity	Min			1.43E-07		1.43E-
	Max			2.27E-04		1.08E-
	Ave			8.12E-05		6.31E-
Permeability (m/d)	Min	56.94	0.65	0.02	0.03	0.07
	Max		3.38	11.59	86.73	2.29
	Ave		2.31	0.86	36.16	1.04

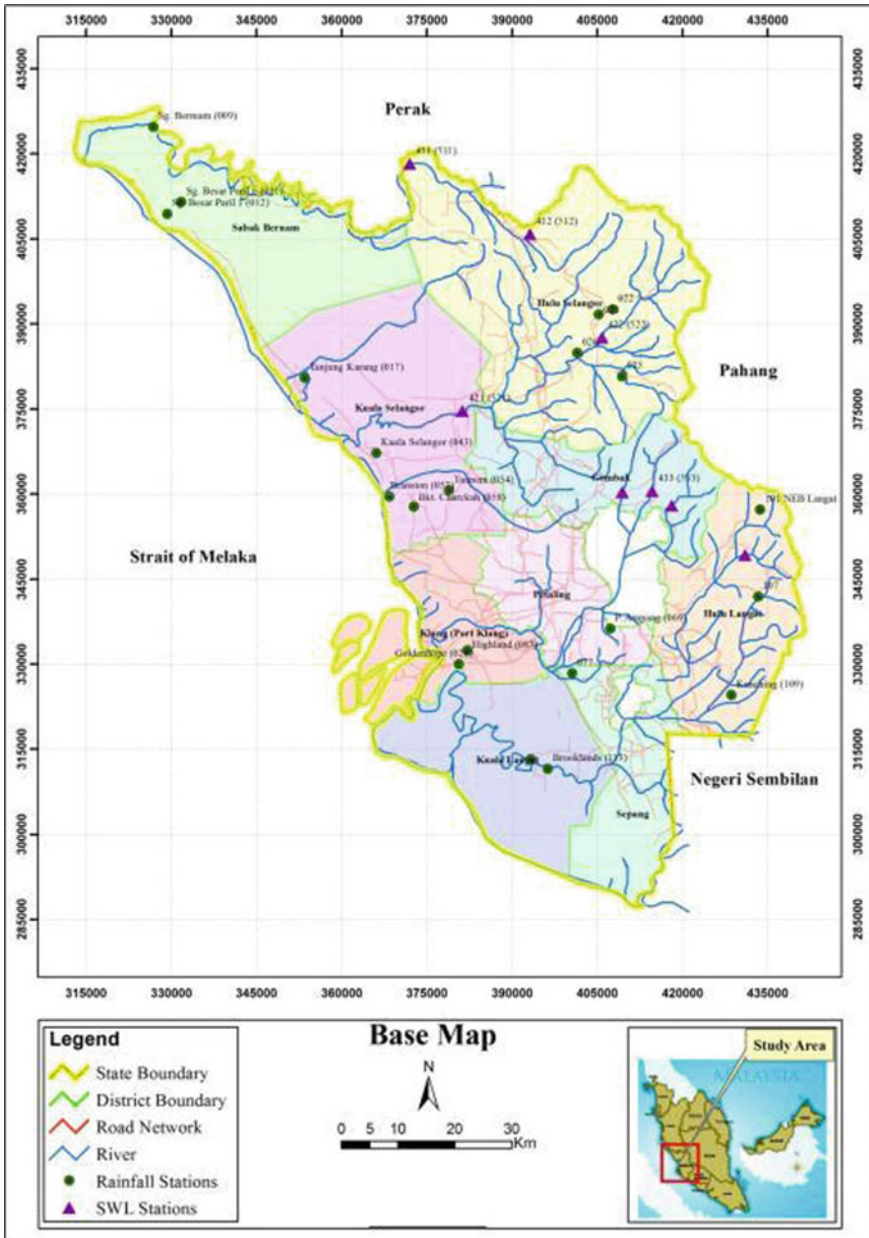


Fig. 2 Base map of the study area

four main river basins in the Selangor State, namely Bernam River, Selangor River, Klang River and Langat River. All the four river systems flow in the west direction and ultimately discharge into the Straits of Melaka as shown in Fig. 3.

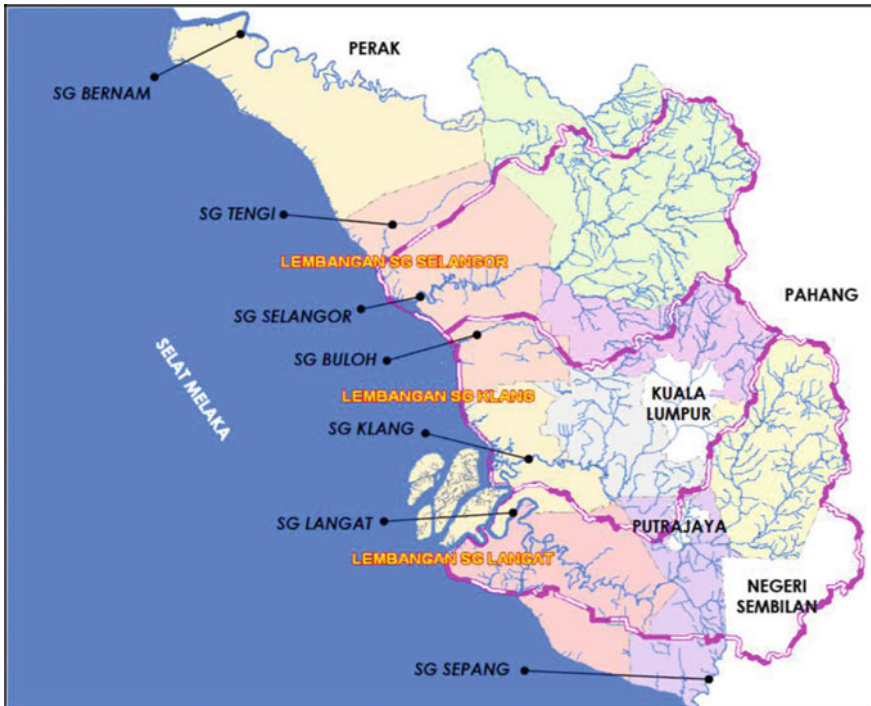


Fig. 3 Major river system of Selangor State

1.5.1 Bernam River Basin

Bernam River Basin is an interstate river which drains the southern part of Perak State and northern part of Selangor State. It has a length of about 200 km and a total basin area of 3335 km² (including the Tengi River system in Selangor State and the coastal flats as in EPU 2000 Study).

The main tributaries of Bernam River are Slim River, Dharoi River, Erong River and Trolak River. Bernam River and the main tributaries originate from the main range in the east. The upper part of the basin is mountainous and covered with virgin jungle while the middle part of the basin is mostly agro-forest consisting of rubber trees and oil palms. The river meanders through mostly peat swamp forest at the lower reaches before entering the Straits of Melaka near Sabak Bernam.

1.5.2 Selangor River Basin

Selangor River Basin with a catchment area of approximately 2200 km² emerges from the foothill of Fraser’s Hill and traverses the north-east region of Selangor for 110 km until the coast. The main tributaries are Sembah River, Kanching River,

Kerling River, Rawang River and Tinggi River. The headwaters region of the basin consists of forested foothills and rugged mountains. The middle region is predominantly undulating with vegetative cover comprising rubber trees and oil palms. At the low-lying coastal regions, the river meanders along the peat swamp forest and finally discharges into the Melaka Straits near Kuala Selangor.

There are two water supply dams in Selangor River Basin, namely Selangor River Dam and Tinggi River Dam. The Selangor River Dam has a catchment area of 197 km² and is located in the upper catchment of Selangor River Basin near Kuala Kubu Baru. The dam was completed in mid of year 2003. Under Selangor River Phase 3 Scheme, Selangor River Dam was constructed to provide additional 1100 mld (12.7 m³/s) and enabling the abstraction capacity from Selangor River to be increased from 1900 mld (22 m³/s) to 3000 mld (34.7 m³/s) (Suratman 2003).

Tinggi River Dam has a catchment area of 40 km² and is located in the upper reaches of Buloh River, the first order tributary of Selangor River near Ladang. This dam was designed as part of Selangor River Phase 2 Scheme to regulate the flow at the existing Batang Berjantai water supply intake about 30 km downstream. There is a pumping station of 150 mld capacity to refill the Tinggi River Reservoir from the main stem of Selangor River during the high flow season (Rockwater 1997).

1.5.3 Klang River Basin

Klang River Basin has a total catchment area of about 1280 km² and a length of 120 km. It originates from the main range about 25 km north-east of Kuala Lumpur at an altitude of about 1330 m. As is typical of rivers on the west side of the main range, the rivers flow westerly to eventually enter the Straits of Melaka. The upper catchment is mainly forest on steep lands. At the middle reaches where Kuala Lumpur is located, Klang River captures two major tributaries, namely Batu River and Gombak River. The other major tributaries of Klang River include Ampang River, Kerayong River, Kuyoh River, Penchala River, Rasau River, Damansara River and Rasah River. Klang River Basin is the most heavily built-up area among the four major basins in the state. Urban centres have been sprouting within the basin rapidly for the past ten years. The rubber and oil palm estates as well as ex-mining lands are being converted into suburban centres with high population densities. About 50% of the basin area is currently developed for residential, commercial, industrial and institutional use.

There are at present two dams in the upper catchment: Klang Gates Dam on the main stem of Klang River and Batu Dam on Batu River. Both dams are for flood mitigation and to a lesser extent water supply purposes. The Klang Gates Dam has a catchment area of 77 km². It is located 15 km north-east of FT Kuala Lumpur. Water from this reservoir flows by gravity to the Bukit Nanas Treatment Plant via two steel mains. Klang Gates Dam was raised by 3 m in year 1979 and its total reservoir capacity is 32 MCM. Batu Dam has a catchment of 50 km², and it is a multi-purpose flood control and water supply dam. It is located about 16 km north of FT Kuala Lumpur. The dam has a reservoir capacity of 33.6 MCM for potable

water supply to Klang Valley. Another dam, Subang Lake or Meru Dam is located at the lower catchment of Klang River, about 30 km west of FT Kuala Lumpur. It serves as direct water sources for areas surrounding the Klang area.

1.5.4 Langat River Basin

Langat River Basin has a total catchment area of approximately 2395 km². It comprises three major tributaries, namely Semenyih River, Beranang River and Labu River. Langat River Basin occupies the southernmost region of the state with part of the catchment intrudes into the neighbouring State of Negeri Sembilan in the south-east corner. Langat River headwater starts from the north-east of the basin, flows southwesterly and joined with Semenyih River after Bangi town. After the confluence with Semenyih River, the river changes its course to a westerly direction to meander towards the coast and discharges into the sea via the north and south estuaries. The north estuary flows into the straits known as Selat Lumut which is the waterway between the mainland and Pulau Indah (formerly Pulau Lumut). The south estuary flows directly into the open sea of the Straits of Melaka. The upper catchment is generally rugged mountain terrain with multiple land use covers. The lower catchment of the river is generally low-lying swampy land with some defunct mining lands.

There are two dams, namely Langat Dam and Semenyih Dam, located at the upper reaches of the river system. Langat Dam is located at the upstream of Langat River with a catchment area of 41.1 km² while Semenyih Dam at the upstream of Semenyih River has a catchment area of 56.7 km². Both dams have been constructed primarily for water supply purposes. Both dams serve as regulating reservoir scheme where controlled releases are made from an impounding reservoir to supplement the river flows during periods where the river flows are deficient.

2 Data Analysis

An integrated approach has been taken incorporating the land and water ecosystem, interaction between the surface and groundwater of the area to assess the groundwater resources.

2.1 Groundwater Availability

Basically, there are no sources of drinking water on Earth that are not polluted. Rainfall cleanses the atmosphere as it forms and falls. As a result, rainfall contains organic compounds, dissolve acids and also heavy metals such as mercury and selenium in many areas. Groundwater which is somewhat filtered and generally

contains fewer quantities of pollutants than surface water may itself be polluted by ground releases of toxicants and by pollutants produced by chemical reactions in the water and soil as well.

2.2 Borelog Location

Existing geological features and lithological data of the study area have been collected from the Selangor Water Management Authority (LUAS), Minerals & Geoscience Department Malaysia (JMG) and other available sources and processed. A total of 320 nos. of borelog data have been collected during this study. The quality of borelog data has been checked, and finally 141 nos. of data have been selected to identify the geology of the study area. Borelog location map of the study area is shown in Fig. 4.

2.3 Groundwater Quality Data

The groundwater monitoring wells located in the study area, which are not uniformly distributed and inadequate for the study. The frequency of data collections from this well was once a year which is not sufficient for modelling purposes. Under Japan International Cooperation Agency JICA was study (2002), 15 nos. of monitoring well was installed in the part of the Langat basin area and collected data in 2002. Considering the urgency of data in model development an attempt was made to collect data from existing monitoring well. As a consequence, 15 nos. of monitoring well was selected, and primary data were collected for 3 months. The locations of the wells for primary data collections are given in Fig. 5.

After necessary quality checking, these data have been used in groundwater quality in compare to Ministry of Health Malaysia Standard (MOH STD) for drinking water of groundwater of the area. In order to assess the suitability of groundwater for different uses, a hydro-geochemical study has been carried out. Groundwater quality data for 15 stations have been collected by Japan International Cooperation Agency (JICA) and 3 sample wells have been used for the analysis based on 22 parameters water quality for this study. The 3 sample wells were selected in Fig. 6.

This study was to compare on Japan International Cooperation Agency (JICA) data and our recent data sampling with 22 parameters. Figure 6 shows that 3 points of monitoring well stations have been selected for this study.

The results of groundwater quality data show that, iron contents have exceeded the value given by Ministry of Health (MOH) Standard for drinking water which is less than 1.0 milligrams per litre (mg/l). Nevertheless, based on the iron for the all

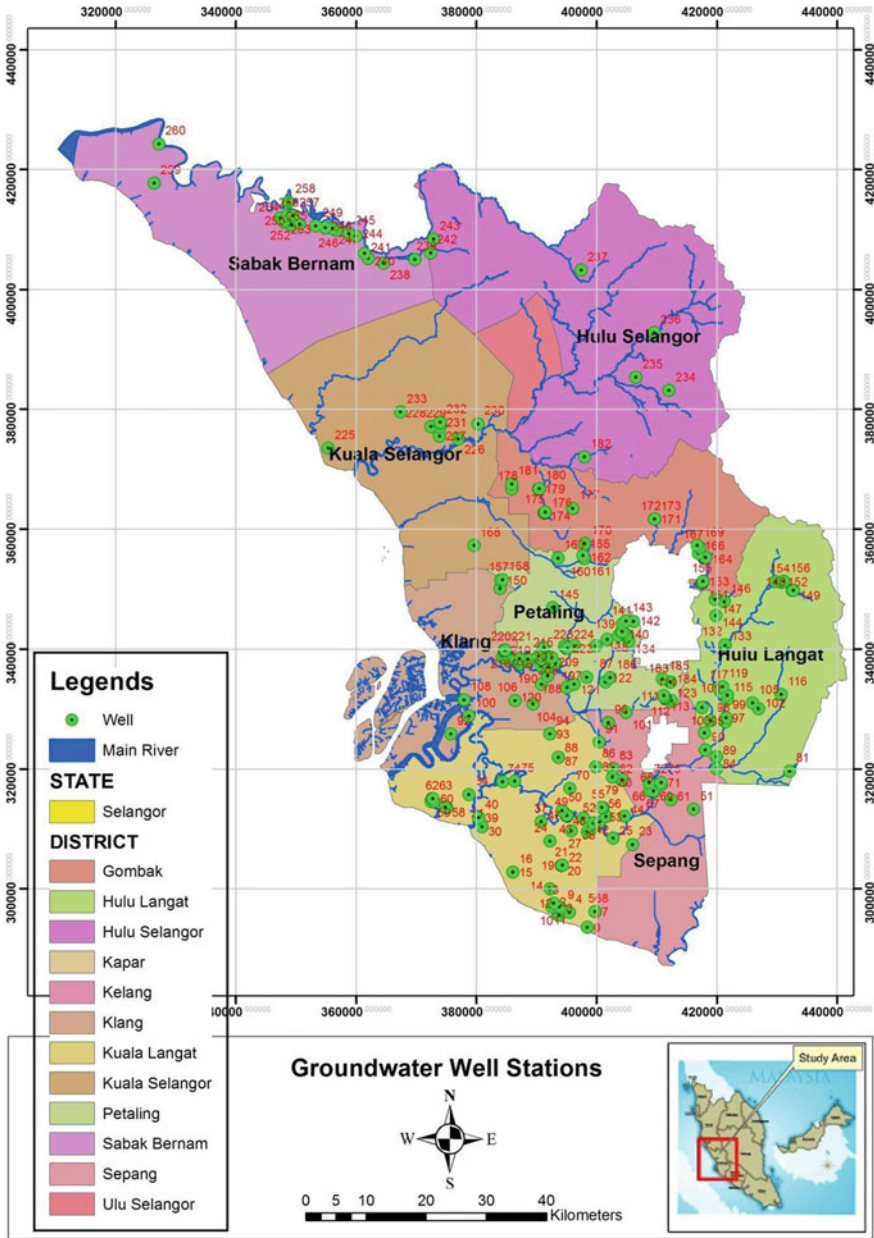


Fig. 4 Locations of borelog data in 2010

areas, respectively, Kapar, Dengkil and Rantau Panjang were high compared to the permitted level. The iron level in groundwater at Rantau Panjang was 7.78 mg/l followed by Dengkil with 4.05 mg/l and the lowest was Kapar with 1.2 mg/l.

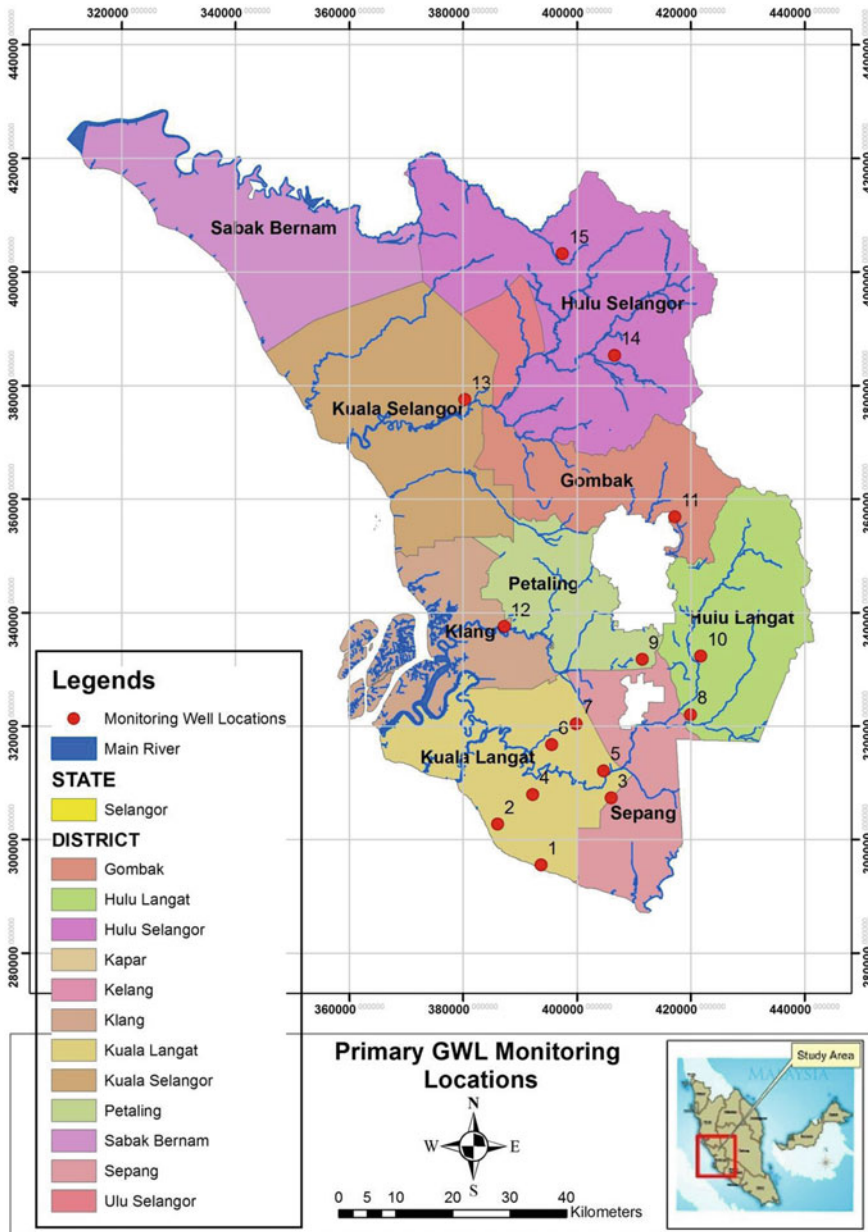


Fig. 5 Primary groundwater level monitoring station

At concentrations found in most natural water and at concentrations below aesthetic objective, iron is not considered a health risk. Water with high concentration of iron may cause staining of plumbing fixtures or laundry. Furthermore,

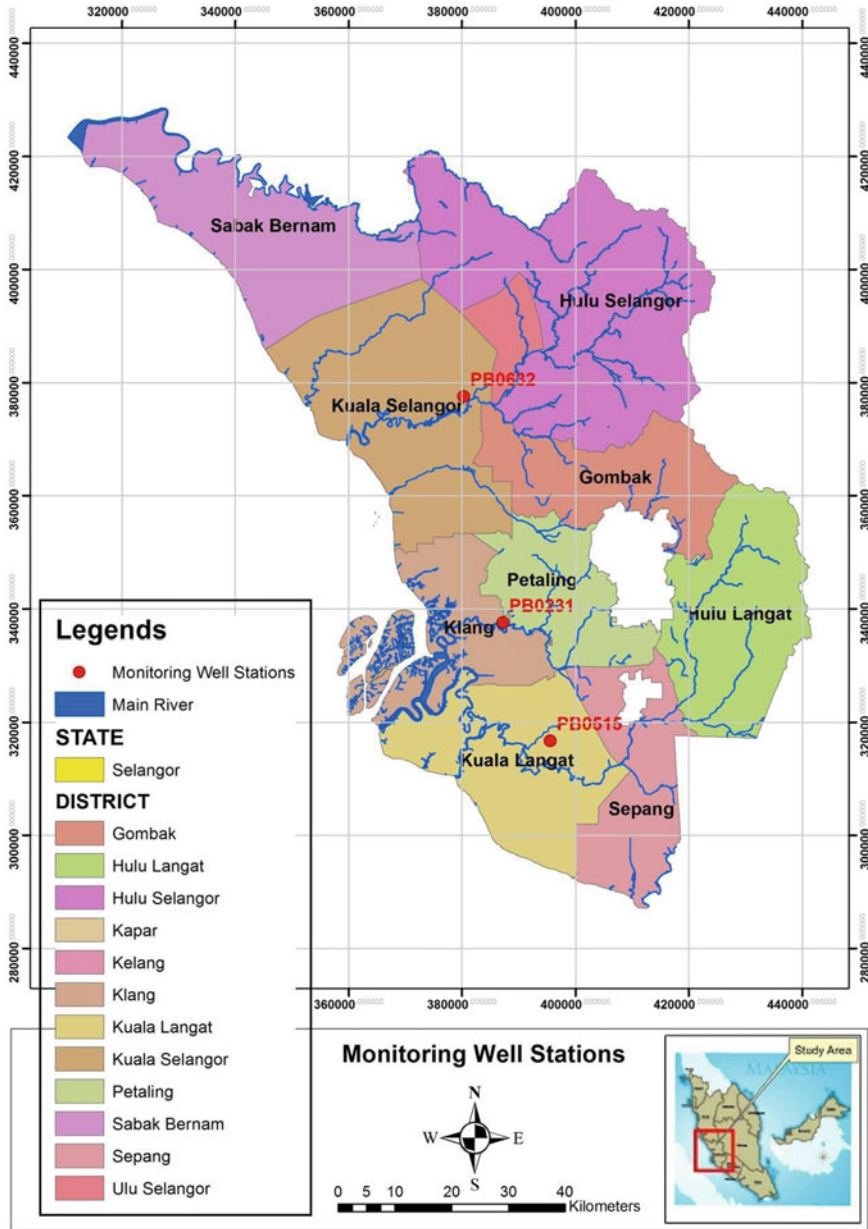


Fig. 6 Monitoring well stations

iron can collect and block pipes or fixtures and produce colour, taste and rust flakes in water. The most common sources of iron in groundwater are naturally occurring such as from weathering of iron bearing minerals and rocks. Industrial effluent, acid

mine drainage, sewage and landfill leachate may also supply iron to local groundwater. The level of iron at Rantau Panjang was recorded as the highest resulted from the rapid development of the area and the activities from the nearby industrial zone.

Tables 3, 4 and 5 shows the results of groundwater quality in Kapar, Dengkil and Rantau Panjang, respectively. We can conclude that all 3 points of monitoring well stations that we choose have high potential to produce clean water supply. The results show that all analysed parameters have lower value compared to Ministry of Health (MOH) Standard for drinking water. However, some filtration or ultraviolet lamp treatment for the groundwater might require.

Table 3 Results of groundwater quality data at station PB 231 (Kapar)

No.	Test parameters	Units	MOB STD	NWQS STD	ID Well	
					PB 231	
					Nov 2002	Nov 2015
1	Sulphate	mg/l	250	250	0.8	10.3
2	Total hardness	mg/l	500	250	6.2	54.4
3	Bicarbonate as CaCO ₃	mg/l	–	–	ND (<1)	48
4	Nitrate	mg/l	10	7	4.17	4.99
5	Coliform	cfu/ 100 ml	–	5000	950	1460
6	Manganese	mg/l	0.1	0.5	0.041	0.08
7	Chromium	mg/l	0.05	–	ND (<0.001)	ND (<0.001)
8	Zinc	mg/l	3	5	0.04	0.1
9	Arsenic	mg/l	0.01	0.05	ND (<0.001)	ND (<0.001)
10	Cadmium	mg/l	0.003	0.01	ND (<0.001)	ND (<0.001)
11	Calcium	mg/l	–	–	2	2.1
12	Mercury	mg/l	0.001	0.001	ND (<0.001)	ND (<0.001)
13	Magnesium	mg/l	–	–	0.3	1.3
14	Sodium	mg/l	200	–	2.1	4.6
15	Potassium	mg/l	–	–	0.9	1
16	Selenium	mg/l	0.01	0.01	ND (<0.01)	ND (<0.01)
17	Chloride	mg/l	250	200	3.4	10.2
18	Phenols (total)	mg/l	0.002	10	ND (<0.002)	ND (<0.002)
19	Total dissolved solids	mg/l	1500	1000	18	41
20	Iron	mg/l	1	1	0.3	1.2
21	Copper	mg/l	1	0.02	0.12	0.18
22	Lead	mg/l	0.05	–	0.013	0.064

Table 4 Results of groundwater quality data at station PB 515 (Dengkil)

No.	Test parameters	Units	MOH STD	NWQS STD	ID Well	
					PB 515	
					Nov 2002	Nov 2015
1	Sulphate	mg/l	250	250	0.3	1.4
2	Total hardness	mg/l	500	250	314	386
3	Bicarbonate as CaCO ₃	mg/l	–	–	536	582
4	Nitrate	mg/l	10	7	0.86	2.6
5	Coliform	cfu/ 100 ml	–	5000	444	675
6	Manganese	mg/l	0.1	0.5	0.67	0.52
7	Chromium	mg/l	0.05	–	ND (<0.001)	ND (<0.001)
8	Zinc	mg/l	3	5	ND (<0.01)	0.1
9	Arsenic	mg/l	0.01	0.05	ND (<0.001)	ND (<0.001)
10	Cadmium	mg/l	0.003	0.01	ND (<0.001)	ND (<0.001)
11	Calcium	mg/l	–	–	30.2	41.6
12	Mercury	mg/l	0.001	0.001	ND (<0 001)	ND (<0.001)
13	Magnesium	mg/l	–	–	58	71
14	Sodium	mg/l	200	–	163	187
15	Potassium	mg/l	–	–	42	53
16	Selenium	mg/l	0.01	0.01	ND (<0.01)	ND (<0.01)
17	Chloride	mg/l	250	200	150	210
18	Phenols (total)	mg/l	0.002	10	ND (<0.002)	ND (<0.002)
19	Total dissolved solids	mg/l	1500	1000	960	1264
20	Iron	mg/l	1	1	3.38	4.05
21	Copper	mg/l	1	0.02	ND (<0.001)	ND (<0.001)
22	Lead	mg/l	0.05	–	ND (<0.001)	ND (<0.001)

Table 5 Results of groundwater quality data at station PB 632 (Rantau Panjang)

No.	Test parameters	Units	MOH STD	NWQS STD	ID Well	
					PB 632	
					Nov 2002	Nov 2015
1	Sulphate	mg/l	250	250	7.5	10.2
2	Total hardness	mg/l	500	250	5.5	6.2
3	Bicarbonate as CaCO ₃	mg/l	–	–	3	7
4	Nitrate	mg/l	10	7	0.04	0.28
5	Coliform	cfu/ 100 ml	–	5000	40	64
6	Manganese	mg/l	0.1	0.5	0.06	0.08

(continued)

Table 5 (continued)

No.	Test parameters	Units	MOH STD	NWQS STD	ID Well	
					PB 632	
					Nov 2002	Nov 2015
7	Chromium	mg/l	0.05	–	ND (<0.001)	ND (<0.001)
8	Zinc	mg/l	3	5	0.1	0.1
9	Arsenic	mg/l	0.01	0.05	0.01	0.04
10	Cadmium	mg/l	0.003	0.01	ND (<0.001)	ND (<0.001)
11	Calcium	mg/l	–	–	2	2
12	Mercury	mg/l	0.001	0.001	ND (<0.001)	ND (<0.001)
13	Magnesium	mg/l	–	–	0.7	1.9
14	Sodium	mg/l	200	–	4.3	6.6
15	Potassium	mg/l	–	–	3.1	3.4
16	Selenium	mg/l	0.01	0.01	ND (<0.01)	ND (<0.01)
17	Chloride	mg/l	250	200	2.2	3.4
18	Phenols (total)	mg/l	0.002	10	ND (<0.002)	ND (<0.002)
19	Total dissolved solids	mg/l	1500	1000	29	41
20	Iron	mg/l	1	1	6.1	7.78
21	Copper	mg/l	1	0.02	ND (<0.001)	ND (<0.001)
22	Lead	mg/l	0.05	–	0.005	0.014

3 Conclusion

Groundwater, a valuable natural resource, has become an important source of water to meet the increasing requirement for domestic, industrial and agricultural needs. Surface water, such as rivers, lakes and drainage areas, in several places becomes inadequate or even unavailable due to several factors which is rapid increase in demand due to population growth, industrial or agricultural expansion, deteriorating quality of surface sources and low flow of surface source during prolonged droughts.

As a result of these factors, a limitation on the availability and capacity of the surface water supply is being experienced. Groundwater is thus considered the only logical alternative to supplement the supply. In areas where there is a total lack of surface source, groundwater may be the only source of supply.

Considering the fact that groundwater is part of the hydrologic cycle, proper water management procedures, planning and policies can be achieved only through an integrated approach involving both surface water and groundwater. The study was thus aimed to determine the availability of groundwater resources of Selangor. Information and data for a holistic and comprehensive management of groundwater resources for sustainable development were collected using GIS that can be implemented and integrated based on the quantity and quality monitoring

(Mohamad 2011). Impact assessment of groundwater abstraction and land use change for future studies was also considered. From the analysis, we can conclude that the level of water quality data for all wells that was selected for monitoring remains good and suitable for drinking water supply. However, due to rapid development and industrialization as well as agricultural development, there is an increasing threat of pollution to groundwater. Groundwater degradation occurs over a long term which is a potential matter for argument.

4 Recommendations

Potential adverse impacts which arising from groundwater extraction on the environment in this area would primarily involve land subsidence and migration of brackish water to the fresh deep aquifer layer. These effects will occur in the long term if the development of groundwater resources in the areas is not managed in the sustainable manner. Therefore, we can minimize or control the impacts with the sustainable management.

Data accessibility on water wells drilling company which is actively involved in groundwater utilization, usually not being publish or release to the public. The related agencies or state water authorities need to make an effort to compile and legitimate the data. The distribution and numbers of groundwater sampling locations are not sufficient to derive the baseline status of water quality. An attempt has been made under this study to get preliminary idea about the water quality index (WQI).

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