SITE CHARACTERIZATION OF SURFACE AND SUB-SURFACE SPATIAL DATA IN PRODUCING RIVERBANK FILTRATION SITE SUITABILITY MAP

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ρ	resistivity
ρ_a	apparent resistivity
k	geometric factor
I	electric current
v	voltage
r	distance between the current electrodes
θ	refraction angle
K	kappa coefficient
mA	mega ampere
q_c	cone resistance
f_s	sleeve friction
u	pore pressure

LIST OF ABBREVIATIONS

1-D	1 Dimensional
2-D	2 `Dimensional
3-D	3 Dimensional
AOI	Area Of Interest
BH	Bore Hole
CPT	Cone Penetration Test
DC	Direct Current
DOE	Department Of Environment
EFCS	Enhanced Field Computer System
ERDAS	Earth Resources Data Analysis System
GCP	Ground Control Point
GIS	Geographical Information System
GL	Ground Level
GPR	Ground Penetrating Radar
IP	Induce Polarization
IRTP	International Reference Test Procedure
ISODATA	Iterative Self Organizing Data Analysis Technique
ISSMFE	International Society of Soil Mechanic and Foundation Engineering
JMG	Jabatan Mineral dan Geosains
JUPEM	Jabatan Ukur dan Pemetaan
LED	Laplacian Edge Detection
PDP	Pole Dipole

PZ	PieZocone
RBF	River Bank Filtration
RDMMS	Relational Database Management System
RMS	Root Mean Square
RMSE	Root Mean Square Error
RSO	Rectified Skew Orthometric
SAS	Signal Averaging System
SBT	Soil Behavior Type
SP	Self-Potential
SPT	Standard Penetration Test
TIFF	Tagged Image File Format
USCS	Unified Soil Classification System
UTM	Universal Traverse Mercator

PENCIRIAN TAPAK PERMUKAAN DAN SUB-PERMUKAAN DATA SPATIAL DALAM MENGHASILKAN PETA KESESUAIAN TAPAK UNTUK PENAPISAN TEBING SUNGAI

ABSTRAK

Kaedah penderiaan jauh, sistem maklumat geografi (GIS) dan kaedah kerintangan elektrik telah digunakan di dalam kajian ini bertujuan menghasilkan peta kesesuaian tapak bagi menentukan penapisan tebing sungai untuk kajian kes di Jenderam Hilir. Imej GeoEYE-1 beresolusi 2012 telah dikelaskan kepada enam menggunakan kaedah pengkelasan berselia yang menggunakan teknik kebolehjadian maksimum. Analisis yang lebih lanjut mengenai klasifikasi imej telah dijalankan menggunakan kaedah GIS seperti hamparan, penimbalan dan analisis bertindan untuk mengenalpasti lokasi penapisan telaga tepi sungai berdasarkan jarak lokasi dengan sungai dan kawasan pembangunan. Hasil klasifikasi GeoEYE-1 menunjukkan ketepatan keseluruhan ialah 89% dengan statistik kappa sebanyak 8.864. Dalam kajian subpermuakaan, kaedah keimejan electrik telah digunakan untuk mengenalpasti kewujudan akuifer dan menghuraikan subpermukaan tanah. Imej kerintangan elektrik telah menunjukkan litologi tanah liat berpasir kepada kelodak berpasir di kedudukan lebih daripada 3 m. Variasi rintangan songsang dengan kedalaman menunjukkan akuifer berpotensi berlaku dalam kebanyakan zon pasir berkelodak dalam perangkap dan dibahagian bawahnya. Berdasarkan litologi, potensi akuifer mengandungi air terperangkap pada kedalaman 3 m di mana ianya hampir kepada keputusan tafsiran. Satu peta kesesuaian tapak telah dihasilkan dan lokasi telaga penapisan air tebing sungai telah dikenalpasti. Peta kesesuaian tapak juga menunjukkan bahawa lokasi lubang telaga sedia ada di tapak kajian berada di kedudukan yang sesuai.

SITE CHARACTERIZATION OF SURFACE AND SUB-SURFACE SPATIAL DATA IN PRODUCING RIVERBANK FILTRATION SITE SUITABILITY MAP

ABSTRACT

Remote sensing, Geographic Information System (GIS) and electrical resistivity technique were used in this study to develop the site suitability map for river bank filtration (RBF) locations for a case study in Jenderam Hilir, Dengkil. A high resolution 2012 GeoEye-1 satellite image was classified into six classes using the supervised maximum likelihood classification process. The classified image was further analyzed using GIS technique such as overlaying, buffering and Boolean analysis, to identify the suitability of a RBF location area based on location, distance from the river and distance from built up area. The classified image results show that the overall accuracy is 89% with kappa statistic of 0.864. For the subsurface profile, the electrical images method was used for investigating the aquifer existence and to evaluating the extent of soil subsurface. Electrical-imaging resistivity results showed the lithology of sandy clay to sandy silt sediments at more than 3 m deep. From the inverse model of resistivity variation with depth indicated the occurrence of potential aquifer mostly in silty sand zones within the traps and below it. Based on lithology, a potential water-bearing aquifer was identified at a depth of 3 m depth which is good agreement with interpreted results. A site suitability map was developed and RBF locations were identified. The suitability map also coincides with the existing borehole location at study area.

CHAPTER 1 INTRODUCTION

1.1 Background

Clean drinking water is one of the most pressing global environmental and health problems of our time. As the world's growing population puts greater demands on the available supply of high quality drinking water, new technologies such as membrane filtration, soil aquifer treatment, and advanced oxidation have emerged. Although these new technologies can successfully treat and improved the quality of the water (Shamrukh and Wahab, 2008). However, higher initial and operational cost have been cited to be one of the main reason on why this methods have not been widely used (Shamrukh and Wahab, 2008).

In Malaysia, the main source of water supply for domestic and industrialized usage are coming from the surface waters that are flowing in the main river and its tributaries. As most of the water intake structures located nearby the river, riverbank filtration (RBF) system has become one of the promising alternative for the water operator (Shamrukh and Wahab, 2008).

Riverbank filtration which is relatively inexpensive use the natural soil of the riverbank as the filtration media to remediate and improved the quality of the surface water from the river. In addition to being low cost and efficient alternative for the water treatment process, RBF is also considered as an efficient method for the removal of various physical, chemical and biological contaminants present in the river water (Shamrukh and Wahab, 2008). Although RBF is widely accepted technology in many countries such as Germany, Belgium and Korea its effectiveness depends on numerous factors mainly the aquifer characteristics such as the soil permeability, the land use along the river and also the surrounding environment (Shamrukh and Wahab, 2008). Therefore, the selection of the suitable RBF site is one of the main issues to ensure the sustainable and effectiveness of the RBF system.

The thesis presented on site characterization of surface and subsurface to identified the suitable location of RBF.

1.2 Problem Statement

The conventional method on finding good RBF location usually by using a site investigation technique which a process of obtaining and gathering relevant subsurface information of the proposed site. The drilling method is a frequently used method to search RBF wells, which produces a single lithology profile of the subsurface profile. Every drilling work requires high implementation costs and time consuming and restricted to small area also an intrusive approach. Risk of failure if the drilled location does not indicate the suitable characteristics for RBF purposes. To overcome this issue, the geophysical method which is 2-D electrical resistivity technique is a good option, which non-intrusive and cost effective technique. The 2-D electrical resistivity technique are used to investigate the subsurface profile by identifying the content of soil, bedrock, aquifer, faults, groundwater and boulders from electrical resistivity measurements made at the ground surface. The 2-D electrical resistivity technique was applied as a tool to extent the lithology profile under the study area to create a multidimensional map of subsurface profile. Hence, by determining the potential of aquifer based on subsurface profile the suitable location of RBF can be determine.

Surface characterization is important to determine suitable areas for RBF sites with suitable site characteristics suit on the environment, utilities, geography, geology, hydrological and buffer zone area. Spatial analysis can be used to facilitate the work, especially for spatial data such as remote sensing and GIS analysis technique. Remote sensing and Geographical Information System (GIS) techniques can be used to identify the surface characteristics for RBF site suitability location for a large area. Remote sensing can be used to derive information for the top layer of the soil, location of the fracture, recharge and discharge areas. Remote sensing can be also used to extract surface information, derive and infer soil properties, and integrate the satellite data into a GIS framework. With the availability of land use and land cover surface terrain by remote sensing data, together with GIS analysis, it is capable to plan and manage the land use suitability mapping for various uses of natural resources and nature conservation. Therefore, by the integration of remote sensing, GIS and electrical resistivity technique will provide a good systematic approach to optimize the RBF site selection process.

1.3 Aim and objective

The aim of this study is to produce a RBF site suitability map, based on spatial data analysis, and geophysical method. Therefore the following objectives are:

1. To investigate using Remote Sensing and GIS to determine site characteristics suitable for RBF site location.

2. To determine the soil profile at riverbank and under riverbed suitable for bank filtration.
3. To produce a 3D geological profile suitable for RBF.
4. To produce a RBF site suitability map.

1.4 Scope of study

The study is define to facilitate the generation of a site suitability map indicating a suitable study area for riverbank filtration. The study was divided into two phases which is the evaluation of surface and the subsurface characterization. The scope of work for surface characterization study is by remote sensing analysis and GIS technique, while for subsurface characterization is done using resistivity technique.

Remote sensing analysis was conducted by using high resolution satellite image which were classified for land cover and land use. ERDAS 9.1 software is used for image processing and Arc Map 10.1 software is used as the main GIS software. Field work is to be conducted to assist in the classification and for reference data compilation. The resistivity study was divided into two phases which are site surveying work and analysis. The resistivity survey was conducted to interpret the subsurface profile at the selection site and analyze using RES2DINV and Surfer 8 software.

1.5 Study area

Three rivers were selected by USM LRGS research based on the pollution level, location and soil characteristic, i.e Langat River, Sungai Perak and Sungai Kerian. In this study, Langat River was chosen based on the availability of existing lithology data for validation of resuls. The study is located between Jenderam Hilir River and Langat River.

The Langat River shown in Figure 1.1, is located in Selangor and classified based on Department of Environmental (DOE) Water Quality Index Classification as Class I and Class II, which indicates clean and slightly polluted. Furthermore, the location of the river is situated in the Langat basin area. The nearest town is Dengkil which located south of Putrajaya. The main tributary that contributes to the study area is a small section of the Langat River which is 5.6 km long. The main tributary of the Langat River is Semenyih River and Labu River. There are several water intakes and treatment plants along the river, and in some cases were shut down due to serious river pollution which affected water supply services and economic activities of the industries.

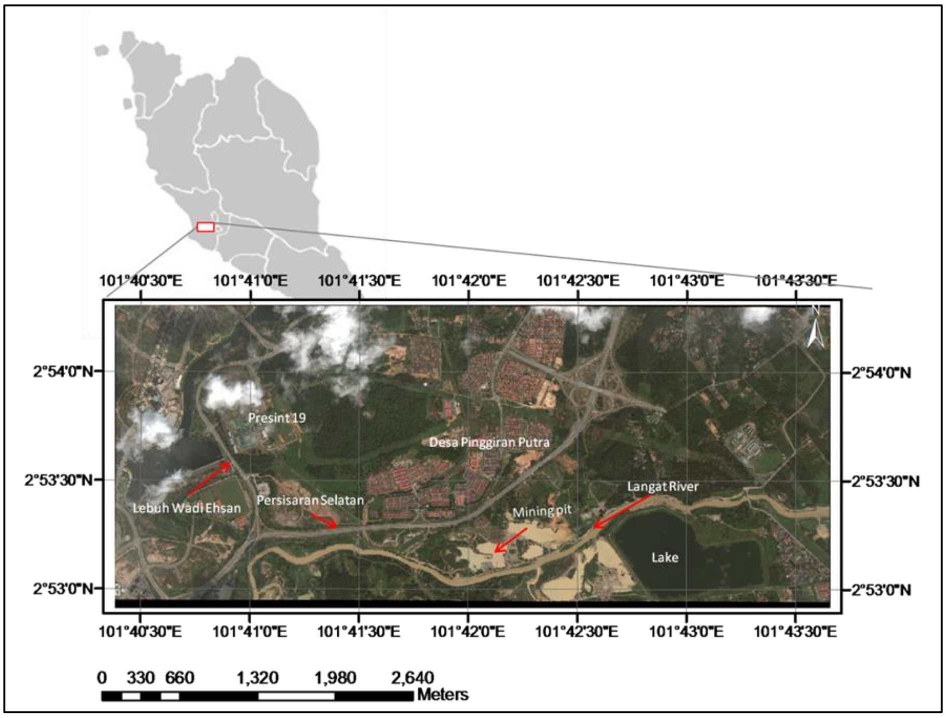

Figure 1.1 Location of study area along the Langat River acquired from GeoEYE-1 satellite imagery 2012

The location of the study area is shown in Figure 1.2 located approximately at latitude 2º53’28.4” N and longitude 101º42’4.6” E of latitude shown in Figure 1.2.

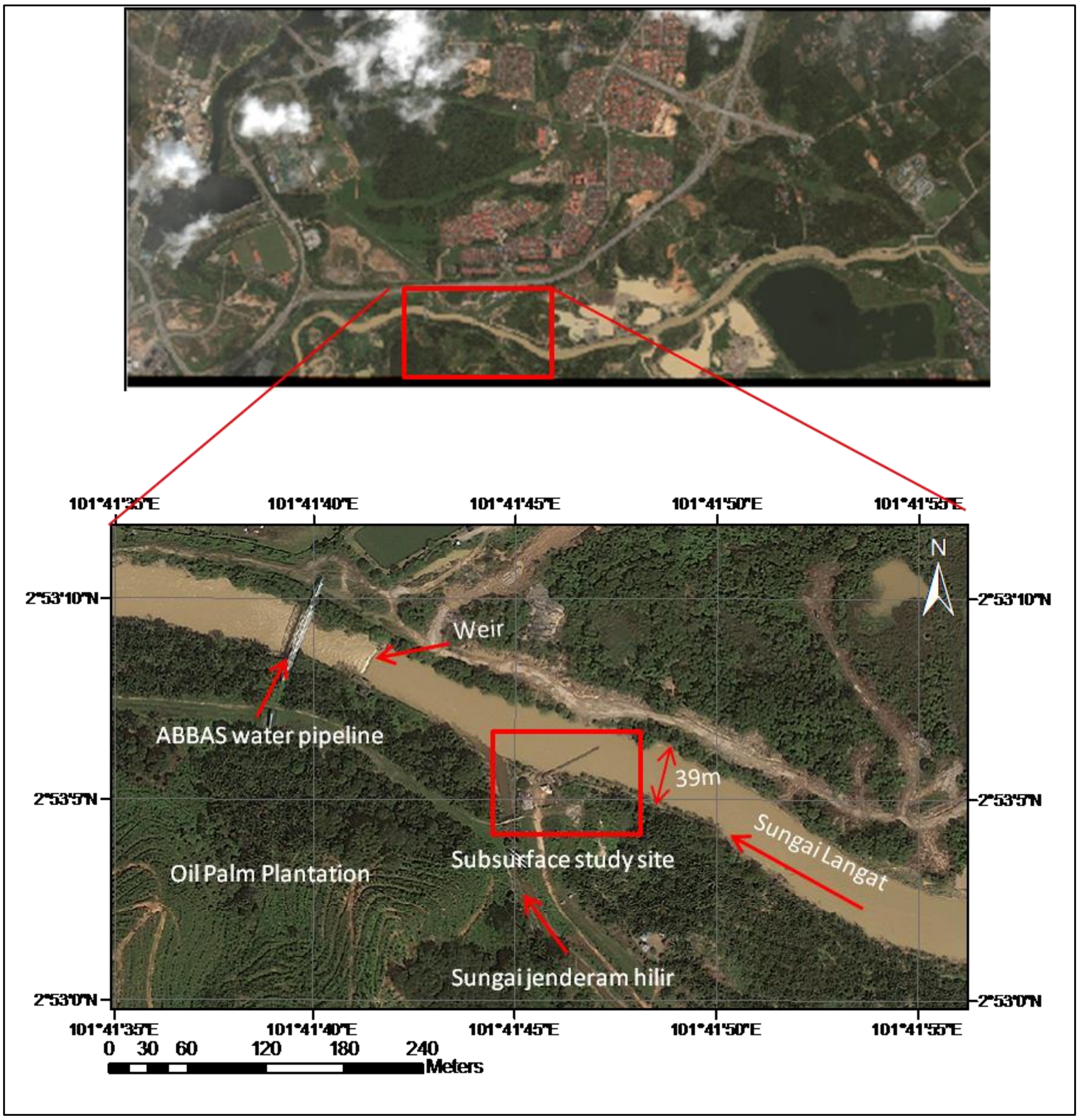

Figure 1.2 Study area focusing on interested subsurface characterization acquired from GeoEYE-1 satellite imagery 2012

1.5.1 Land use and land cover type

The land use and land cover types of the study area were surveyed to determine the surface characteristic features. The data can be used as training data for remote sensing classification. The study area was then classified according to the major land use types namely Forest, Agriculture, Water Bodies, as built Land, Rangeland, Barren Land and mining area based on land use map of peninsular Malaysia.

a) Forest/palm oil

The forest with non-deciduous tree at Dengkil as shown in Figure 1.3. The forest area is quite small due to agricultural activities such as palm oil estate.

(a) (b)

Figure 1.3 Forest and palm oil area in Jenderam Hilir, Dengkil

b) Rangeland Area

Rangeland is an area covered by predominantly grasses, shrubs and forbs. The rangeland type's vegetation grows primarily native vegetation, rather than plant established by humans on the land left fallow for a certain period of time. In the study area as shown in Figure 1.4, it can be discovered a suitable area following removal of forest tree for road and dam development previously.

(a) (b)

Figure 1.4 Rangeland area including grassland and vegetation in Jenderam Hilir, Dengkil

c) Water Bodies

The water bodies in this study include river, streams, lake, ponds and the wetland area. This water bodies as shown in Figure 1.5 will be classified as shallow water and deep water (Figure 1.5).

(a) (b)

Figure 1.5 Water bodies, including deep water and shallow water in Jenderam Hilir, Dengkil

d) Built-up

Figure 1.6 shows typical built-up in the study area, which is characterized by large roof areas and surrounded by expansive areas of open space, paved area or concrete building. The surroundings Langat River was a rural area that only pipeline across the Langat River and a few residences area can be seen.

(a) (b)

Figure 1.6 Houses and Pipeline bridge which are part of the as built land in Jenderam Hilir, Dengkil

e) Barren Land

At Dengkil, it is an ex-mining area where large areas are covered with bushes as shown in Figure 1.7

(a) (b)

Figure 1.7 Barren Land and abandoned mining activity in Jenderam Hilir, Dengkil

1.5.2 **Geological aspect**

Figure 1.8 shows that the geology of Langat basin covering 3 areas of mountainous, predominant rock and coastal plain. The mountainous area contain of bedrock that includes Permian igneous rocks, pre-Devonian schist and phyllite (Gobbett et al., 1973). Gobbett et al. (1973) stated that Phyllite in the mountainous area are called Hawthornden Formation, which is highly deformed and has passed through two phases of deformation. At the foothills, there are predominant rocks which include Permo-Carboniferous meta-sandstone, quartzite, slates, phyllites, and quartz schist of Kenny hill Formation. Gobbett et al. (1973) mention that the coastal plain area possess of quartenary deposits results from the weathereing process of four types of formation i.e Simpang, Kempadang, Gula, and Beruas Formation where it is unconformable overlay on the eroded bedrock that consist of gravel, sand, silt and clay that have been unconsolidated by the Palaeocene with the Holocene period. It is progressively grown younger and thicker toward the coast (Gobbett et al., 1973). These sediments usually are downgrade from clay to gravel that was deposited in fluvial and shallow marine environment. At the base of Quaternary strata, coarse to very course sandy gravel of the Simpang Formation (Palaeocene to Pliocene) assumed to be the primary aquifer of Langat Basin. JICA (2001) stated that at the foot hills area the aquifer has a thickness of several meters from 50 to 100m and further toward the coast.

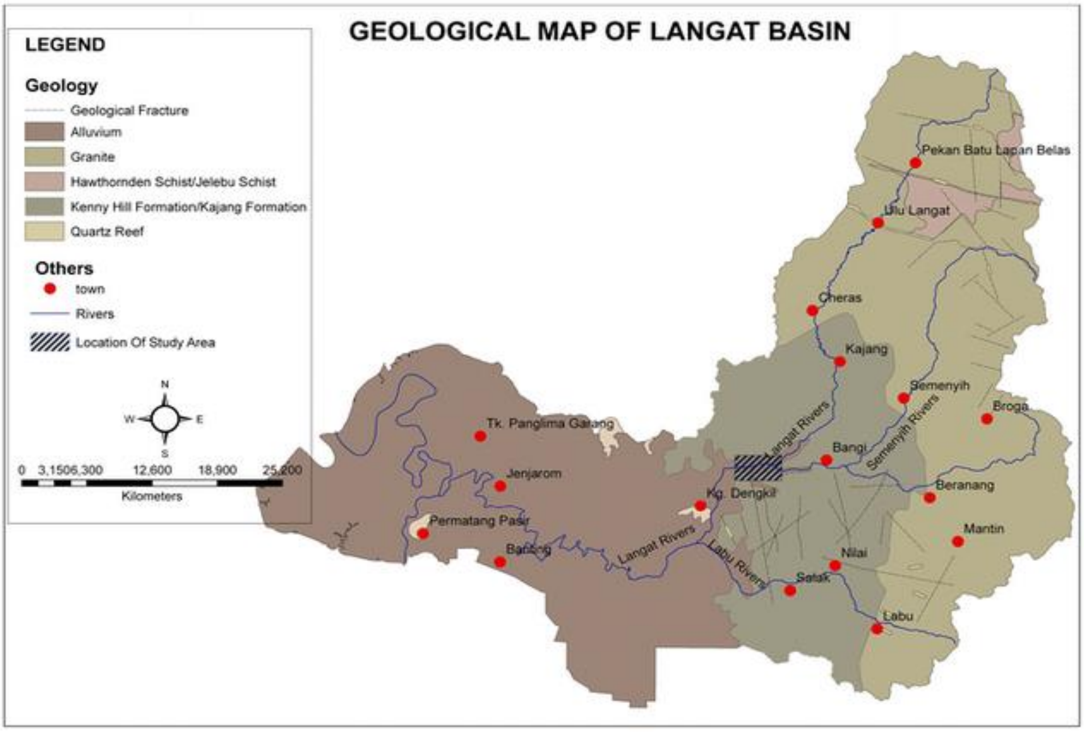

Figure 1.8 Geological map and major river cover the study area as described on the map (Source: Department of Mineral and Geosciences Malaysia, 3 December 2007)

1.6 Thesis Organization

This thesis is organized in five chapters. Chapter 1 briefly discuss the background, problem statement, aim objectives and study area related to the research study. Following this chapter, a comprehensive literature on the topic of ‘site characterization of surface and sub-surface spatial data in producing riverbank filtration site suitability map’ is reviewed. Chapter 3 explain the methodology adopted to conduct the research. Chapter 4 presents the results of the research with some discussion. Finally, the last chapter concludes the research and state the recommendation for future works.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter explains about the research done by other researcher to obtain the suitable location for riverbank filtration by reviewing some of the parameters with additional techniques from the Geographical Information System (GIS) and resistivity survey from work done by other researcher.

2.2 Riverbank Filtration Technology

Nowadays, clean drinking water becomes one of the global environmental and health issues (Macedonio et al., 2012). Great demands to the availability of high quality drinking water would subsequently increase. There are some new developed techniques for the treatment of water quality, for instance, membrane filtration, soil aquifer treatment, and advanced oxidation (Tufenkji et al., 2002). However, available method called riverbank filtration (RBF) was increasingly being used because of its sustainability, effective and low cost as pretreatment methods before water treatment process (Ray et al., 2003; Shamrukh and Abdel-Wahab, 2008; Tufenkji et al., 2002).

Naturally, the RBF technique allows surface water from an aquifer induced by the hydraulic gradient (Jaramillo, 2012). The water is then collected into collector wells which can be pumped and extracted at a low cost. The RBF is a type of water system that is processed by extracting water from rivers by pumping wells located in the adjacent alluvial aquifer (Jaramillo, 2012). Thus, the well should be located adjacent to the surface water body, and over time it should be able to withdraw enough water from the flow system and induce water from surface source (Ray, 2001). This treatment reacts naturally and it is suitable for people who want safe and healthy but not highly treated, potable and industrial water supplies (Shamrukh and Abdel-Wahab, 2008).

The impurities of river water are impaired through the filtration process in the RBF system (Shamrukh and Abdel-Wahab, 2008). The performance of RBF systems depend on the well type and pumping rate, travel time of surface water to the well, site hydrogeology conditions, quality of water sources, biogeochemical reactions in sediments and aquifer, and quality of background/existing groundwater (Ray, 2001).

2.2.1 **Parameters Effecting Yield in RBF**

The yield in a RBF system is a function of volume of water's available, at which the water can be transferred to the well from the aquifer. It is usually controlled by different factors which are partly influenced by each other. For example, the ability of water to recharge the aquifer is an important aspect to ensure sustainable yield in RBF for the long term effect. However, the hydraulic conductivity of the riverbed can change significantly when mechanical clogging of the riverbed by fine particles that suspended in river water are done and therefore, results in limited recharge to the aquifer (Caldwell, 2006; Schubert, 2006).

There are many factors affecting yield in RBF. Those factors include aquifer characteristics (transmissivity of the aquifer and volume of water available for extraction), site geometry (layout of well) and river hydrology (due to impact of sediment transport and renewal capability of the river), riverbed characteristic (medium of tendency to clog), water quality (the size and amount of suspended particles in the water) and operational data (drawdown, driving head, etc.). Hence, these operation data enable the operational performance of the sites to be compared to site characteristics to help in the understanding of how site conditions affect performance (Caldwell, 2006).

2.2.2 Aquifer characteristic

Aquifer plays an important role in the RBF system and by definition, the aquifer is a water bearing stratum of permeable materials (Renken, 1996).Volume, transmissivity, storativity, and porosity of the aquifer are factors that influence the yield in RBF system (Caldwell, 2006). A brief description of all the factors above are as follows:-

i. The aquifer’s volume holds a critical role in yielding because it determines the quantity of water available for abstraction from a well in the absence of recharge (Taylor et al., 2011). Basically, the volume of aquifer is a function of the saturated thickness, width, and length of the aquifer (Caldwell, 2006). The length of the aquifer is not distinguishable in alluvial aquifers where the aquifer follows the river path (Gorder, 2004). Therefore, the availability of the aquifer will be used to identify the quantity of available water (Caldwell, 2006).

ii. Transmissivity of aquifer is the function of hydraulic conductivity of aquifer medium and the aquifer avalability (Halford et al., 2006). The values are commonly available from pumping tests at RBF sites (Caldwell, 2006). Transmissivity of aquifer is the rate of flow through the entire aquifer due to a unit hydraulic gradient. Meanwhile, the storativity of an aquifer is the amount of water that is released per unit area for a unit drawdown in an unconfined aquifer.

iii. Storativity or storage coefficient is the amount of water pouring out per unit area of the aquifer for given drawdown induced by the pumping wells (Schön, 2006).

iv. The porosity is the ratio of the volume of voids to the total volume of the aquifer material. It influences the velocity at which water moves through an aquifer under a given hydraulic gradient (Caldwell, 2006).

2.2.3 **Site geometry**

The geometry of selection site may impact the capability of RBF to recharge the river water via aquifer and influences the clogging effect (Lacher, 1996; Rehg et al., 2005; Schubert, 2006). The position of well field is basically described simply by their distance from the river along with closeness to river meander. Caldwell (2006) states that the perpendicular length from the river to the center of the well field determines the quantity of river water that a given pumping scheme will cause to infiltrate the aquifer. Hence, the water infiltrated would be expected to be more yield if the well field more closely to the river due to increase of recharge. Nevertheless, this system will be vulnerable to clogging effect because of increasing in velocity at the entrance of riverbed (Caldwell, 2006). As shown in Figure 2.1, high velocity of river flow occurs at the outside bending of the river and therefore, greater shear stress happen than the inside bends

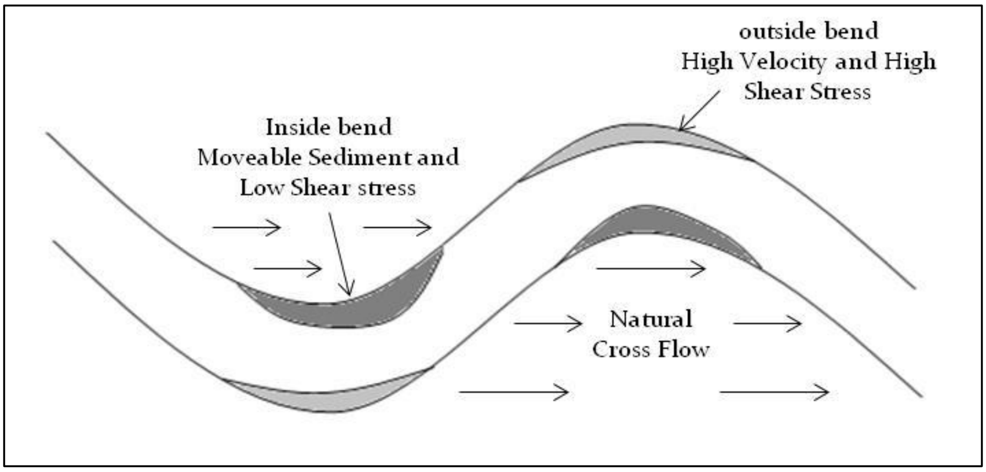

Figure 2.1 River Meander (Caldwell, 2006)

An increase in numbers of applied wells caused an increasing of the riverbank length by a RBF system and this is expected to significantly influence the yield. More wells installed along the riverbank result in longer reach of the river and this process makes the aquifer to increase recharge form. The length of a well is limited by the depth of the aquifer (Hecox et al., 2002).

Clogging can caused lost capacity with dependence on river geometry (Schubert, 2002). When clogging occurs in narrow riverbeds, the infiltration area extends to the entire of the river's length (Caldwell, 2006). On the other hand, the width of the infiltration area grows equally in a wide river (Caldwell, 2006). Therefore, the width and length are depending on the change of discharge over the time.

2.2.4 **River hydrology**

River hydrology affects the ability of the river to recharge the aquifer in RBF systems through its impact on the hydrologic relation between the aquifer and the river. Hydrologic and hydraulic parameters of the river is important including discharge, stage, and shear stress (Caldwell, 2006).

One of the most significant parameters is the bank full discharge. The bank full stage is the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow onto a floodplain (Leopold et al. 1964). Bank full discharge is important because it can be used to estimate the dominant discharge (Knighton, 2014), which is the flow responsible for most sediment the transport over time. If the bankfull discharge is responsible for the most sediment transport, it is reasonable to infer that it would likely be most responsible for removal of clogged areas in RBF systems (Caldwell, 2006).

The clogging and removal processes in a river are controlled by the rivers ability to transport, deposit and re-suspend sediment (Tufenkji et al., 2002). A clogged area is renewed when water flow on the riverbed it will create a shear stress that is capable of re-suspending the clogging sediment (Caldwell, 2006). Thus, the shear stress on the bottom of the river is a key factor that affects yield in riverbank filtration. One of the easiest methods for estimating shear stress by utilizes the water surface profile by measuring river water flow. The total energy in a stream is the sum of the velocity head, pressure head and elevation head. If in a reach, most of the head loss is caused by friction along riverbed and other losses (Caldwell, 2006).

2.3 RBF site selection based on separate field

Site selection for RBF suitability is very important especially to prevent damage to the environment and nature. The various site selection criteria from the available case studies were focused upon the key performance indicators for RBF system (Archwichai et al., 2011). Thus, the identification of suitable site can be simplified and also reduces the cost for research work.

Archwichai et al. (2011) stated that the established key performance criteria for the RBF system site selection include five groups of data sets, namely; hydrology, hydrogeology, water quality, land use in the construction site, and water demand by compilations of various series of thematic maps using the GIS overlay method for site selection screening. Kim and Kim (2008) suggested that the detailed profiling and characterization of an alluvial aquifer are important factors in selecting suitable well sites and well designs.

The geological aspect of the study area are required to identify the soil suitability for RBF (Archwichai et al., 2011). Alluvial aquifer is a precious natural resource because of interactions between surface water and the subsurface. There are many types of alluvial aquifer such as sand and gravel (unconsolidated and semi-consolidated), sandstone, inter bedded sandstone and carbonate, carbonate (limestone and dolostone), volcanic rocks (usually basalt) and crystalline bedrock (granite, gneiss, etc.). An aquifer has a high hydraulic conductivity and in most cases, aquifers are unconfined, except volcanic rock and carbonate rock (Fetter and Fetter, 2001).

2.4 Surface characterization

Surface characterization is important to determine suitable areas for RBF site study where the study area must achieve suitable site characteristic in terms of environment, utilities, geography, geology, hydrological and buffer zone area (Weiss et al., 2003). Nowadays, many engineering techniques have been developed to for site selection in order to minimize the risk of failure during research work. Therefore, to avoid the risk, spatial analysis can be used to facilitate the job such as remote sensing and GIS analysis technique (Zandi et al., 2011). The chosen method will depend on the main objective for optimizing the cost for searching and risk of failure.

2.4.1 **Land use and land cover mapping using remote sensing**

According to McVicar et al. (2003) remote sensing data has a capability to observe a large range of landscape biophysical properties that is important for management and policy. Even so, the internal structure of composition of the landscape, such as soil chemical characteristics, soil management practices cannot be register by remote sensing data. The in-situ measurement and modelling systems of terrestrial processes and climate need to be combined and complemented with remote sensing technique (McVicar et al., 2003)

Remotely sensed data based on a satellite image is usually recorded in digital type as a grid of cells or pixels. Pouncey et. al., (1999) stated that the data file value designated to each pixel is the record of reflected radiation or emitted heat from the terrain's surface at the location as shown in Figure 2.2 .

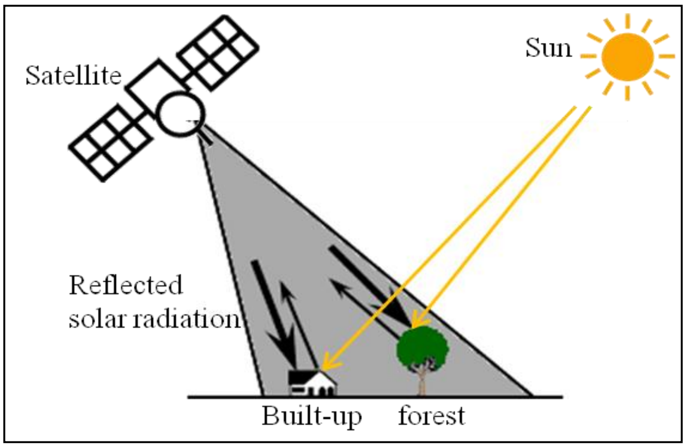

Figure 2.2 The concept of remote sensing (source: CRISP, n.d)

Commercially availability imagery in pixel value represents the radiance of surface in format of digital numbers (DN), which are adjusted to match with a certain range of values for example 0 to 200 in an image of 8 bits (Varlyguin et al., 2001). There are four distinct type of resolutions to be concerned in remote sensing which is: spatial (the area on the ground represented by a pixel), spectral (the spectral wavelength interval that a sensor can record), temporal (how often a sensor obtains imagery of particular area) and radiometric (the number of digital level into which the radiance of the surface recorded by the sensor is divided and expressed, and commonly expressed as the number of bits.

Several satellite images are available from several satellites and sensors such as GeoEye, Ikonos, SPOT, Landsat series, Aster, Quickbird and etc. GeoEye is one of the world's highest resolution commercial Earth-imaging satellites that display unsurpassed georeferencing accuracy (Baraldi et al., 2010; Marjoribanks, 2010).

2.4.2 **Satellite image analysis in remote sensing**

Error still exists in remotely sensed data caused by the environment or random/systematic malfunction of the remote sensing system. Thus, the accuracy assessment is required to assess the quality and statistical characteristic of digital remote sensing data. Exploratory data analysis technique can be assisted for this assessment (Jensen, 1996).

The analysis and processing of satellite image can be refered to the act of examining images for the aim of classifying, detecting, identifying, measuring and evaluating the relevance of physical and cultural objects, their pattern and spatial relationship (Pouncey et al., 1999). Image processing techniques can be characterized into pre-processing, image classification, post processing and evaluation (Jensen, 1996). The procedure for image processing can be found in Pounce et al., (1999) and Jensen, (1996).

Common pre-processing techniques include geometric correction, spatial enhancement and spectral enhancement were discussed by Guindon and Zhang (2002). The author also explains that haze reduction is an important pre-processing step to extract information since spatially varying haze commonly features of archival Landsat TM scenes which can affect the image classification quality.

There are many methods involves the choice of using appropriate method for land use and land cover (LULC) classification that will always depend on characteristic of the image and type of analysis performed (Eastman, 2006a). Eastman (2006b) added that satellite image classification for the land cover categories is based on the fact that land cover types have unique spectral response patterns which can be identified using spectral pattern analysis. Classification can be conducted through the unsupervised or supervised method (Hastie et al., 2005). Even so, the performance of both methods are still lacking where unsupervised training does not ensure that the classification process are sensible for the user and supervised training is a subjective classification mainly because of the interpreter simply categorized without taking cognizance of the full spectral characteristics in the image (Chuvieco, 2002). Therefore, unsupervised and supervised classification can be combined to obtain optimal results especially with large data sets. Chuvieco (2002) gives an example that the unsupervised classification is useful for categorizing the basic classes and supervised classification can be used for further definition of classification. Image classification refers to the extraction of differentiated classes or themes, usually LULC categories, from raw remotely sensed digital satellite data (Qian et al., 2007). LULC classification system in this study is based on the Town and Rural Planning Department (JPBD) land use classification system.

However, evaluation of signatures is an important step for image classifying process and there are some trials to perform where the signature data is a true description of the pixels to be classified for each class. Signature separability can be evaluated based on statistical measure of distance between two signatures by using interpretable method of the Divergence and Transformed Divergence (Pouncey et al., 1999).

Then, non- parametric or parametric classification decision rules are selected. A non-parametric decision rule is not based on statistical descriptors which make the non-parametric properties data's independent. However, if a pixel value is located within the upper and lower limits of a defined nonparametric signature, then this decision rule assigns the pixel to the signature's class (Pouncey et al., 1999). On the other hand, a parametric decision rule is based on the statistical descriptors (mean and covariance matrix) of the pixels that are in the training sample for a certain class. The most likely used is the Maximum Likelihood Decision Rule and accurate of the parametric classifiers. Those two methods are based on the probability of a pixel belongs to a particular class. Otherwise, if there is an important knowledge that the probabilities are not equal for all classes, weight factors can be specified for particular classes. This variation of the maximum likelihood decision rule is known as the Bayesian decision rule (Pouncey et al., 1999). In each input band, the maximum likelihood relies heavily on a normal distribution of the data and tends to over classify signatures with relatively large values in the covariance matrix. The covariance matrix of that signature contains large values if there are large dispersion pixels in a cluster or training sample (Jensen, 1996).

Among other purposes, evaluation of classification accuracy, reduce isolated pixels and improve map representation by classified images which require post-processing. The post processing operation is commonly used to generalize the image through a low pass filter over the classified result and fuzzy convolution during parametric classification by using the distance error image file generated (Pouncey et al., 1999). Land cover maps derived from remotely sensed data inevitably contain errors of various types and degrees. Therefore, it is very important to determine the nature of these errors in order to evaluate their appropriateness of specific uses by both users and producers of the maps (Congalton and Green, 2008).

The error matrix is usually used in reporting the accuracy of maps, derived from remotely sensed data (Congalton and Green, 2008). The accuracy of maps by error matrix was done by comparing the classification to ground truth or other data (existing maps), and calculation of the percentages of accuracy based upon the results of the error matrix (Pouncey et al. 1999). An error matrix technique is suitable for remotely sensed data which is discrete data rather than continuous data. Some work on classification accuracy assessment has focused on factors influencing the accuracy of spatial data, for example the classification scheme, sampling scheme and sample size, and spatial autocorrelation (Congalton and Green, 2008). There are also other important considerations in classification accuracy assessment which include the ground verification techniques and evaluation of all sources of error in the spatial data set.

In the evaluation of image classification, the Kappa coefficient (K) is applied to estimates accuracy that expected to occur by chance (Maingi et al., 2002). The formula for computing the K coefficient is given in the Equation 2.1 (Sim and Wright, 2005)

$$K = \frac{\text{Overall classification accuracy} - \text{Expected classification accuracy}}{1 - \text{Expected classification accuracy}} \qquad (2.1)$$

The Kappa coefficient expresses the proportionate reduction in error generated by a classification process and compared with the error of a completely random classification. Main diagonal elements of the error matrix only been used in overall