UNIVERSITI PUTRA MALAYSIA

RIVERBANK FILTRATION AS A CONJUNCTIVE USE BETWEEN SURFACEWATER AND GROUNDWATER FOR WATER SECURITY

MOHD KHAIRUL NIZAR BIN SHAMSUDDIN

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MOHD KHAIRUL NIZAR BIN SHAMSUDDIN

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January 2019

Chairman : Wan Nor Azmin Sulaiman, PhD
Faculty : Environmental Studies

Climate change has caused limited water resources in many parts of the world. In fact, high occurrences of river pollution in Malaysia have led to the decrease in drinking water resources. This causes the closure of water intakes and water treatment plants which have impacted water supply, and thus, affected economic activities in the manufacturing industry and other sectors. Riverbank filtration (RBF) is one of the solutions to providing raw water for public supply in tropical countries. RBF is natural process using natural soil (aquifer) to treat surface water and seeping from the bank or bed of a river or lake to the pumping wells where, surface water and groundwater were used conjunctively for water supply. In this study, a pilot site consisting of three areas located at Langat river basin, Linggi river basin and Muda river basin based on hydrogeology and land use were monitored. Nevertheless, RBF needed to be assessed on its feasibility based on the local site geological characteristics. Therefore, this research was carried out to fill in the knowledge gap in evaluating the capability of combined use groundwater and surface water using RBF system by using a number of research methods. For that reason, measuring the efficiency of RBF involved geophysical data, sieve (particle size) analysis, pumping test data, isotope analysis, statistical tools, numerical modelling, and water quality data technique. The physicochemical and microbiological parameters of the local surface water and groundwater were analysed before and during water abstraction. Abstraction of water revealed a 5–98 % decrease in turbidity, as well as reductions in HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+}, Al^{3+} and As concentrations compared with those of surface water. In addition, amounts of E. coli, total coliform and Giardia were significantly reduced (99.9 %). However, water samples from test wells during pumping showed high concentrations of Fe^{2+} and Mn^{2+}. From the numerical modelling, the proposed method performs filtration safely and achieves the ideal pumping rate. Results indicate that the migration of river water into the aquifer is generally slow and depends on the pumping rate and distance from well to the river. Most river water arrives at the well by the end of a pumping period of 1 to 5 days. During the 9.7-day pumping period, 33 % of the water pumped from the well was river water based on the distance at 36 m from river, and 38 % of the water pumped from 18 m distance form river throughout 4.6 day was river water. In examining the interaction between the surface water and the groundwater, environmental isotopes like δ^2H and $\delta^{18}O$ were studied primarily. The environmental isotope and hydro-chemical sampling results had emphasised that the area near river basin had a connection with the river and groundwater was actively recharging the near-river shallow alluvial aquifer, via RBF method. The approximate hydraulic conductivity (K) values of samples taken from riverbanks and streambeds, respectively, were then calculated by employing empirical equation methods, pumping test and permeability tests indicated that the value of K was important in clogging processes and the velocities and residence times in the subsoil. Furthermore, samples of groundwater and surface water of standard drinking water quality for both wet and dry seasons have been collected and analysed for various parameters and water indices. Result was indicated that all groundwater and surface water samples can be categorised as excellent and good categories respectively. In conclusion, Malaysia riverbank were suitability of RBF systems had a higher potential area and were able to generate potable drinking water but various method such as geophysical, hydro-chemical, geochemical, stable isotope approaches pumping test, statistical tools and numerical modelling must be priority to applied during the RBF studies. RBF is acceptable as a conjunctive use of surface water and groundwater for national water security applicable during climate change.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SUSUPAN TEBING SEBAGAI KEGUNAAN KONJUKTIF DI ANTARA AIR PERMUKAAN DAN AIR TANAH BAGI SEKURITI AIR

Oleh

MOHD KHAIRUL NIZAR BIN SHAMSUDDIN

Januari 2019

Pengerusi : Wan Nor Azmin Sulaiman , PhD
Fakulti : Pengajian Alam Sekitar

Perubahan iklim telah menyebabkan sumber air yang terhad di kebanyakkan bahagian di dunia. Malah, kejadian pencemaran sungai yang tinggi di Malaysia telah mengakibatkan penurunan sumber air minuman. Ini menyebabkan penutupan muka sauk dan loji rawatan air yang memberi kesan kepada bekalan air, malah, mempengaruhi aktiviti ekonomi dalam industri perkilangan dan sektor lain. Susupan tebing sungai (RBF) merupakan salah satu penyelesaian untuk menyediakan air mentah bagi bekalan air awam di negara-negara tropika. RBF adalah proses semulajadi yang menggunakan tanah asal (akuifer) untuk merawat air permukaan dan air tersebut meresap dari tebing sungai atau dasar sungai atau tasik ke telaga pengepaman di mana, air permukaan dan air tanah digunakan secara gunasama untuk bekalan air. Dalam kajian ini, sebuah tapak perintis yang terdiri daripada tiga kawasan yang terletak di lembangan sungai Langat, lembangan sungai Linggi dan lembangan sungai Muda yang berdasarkan kepada hidrogeologi dan penggunaan tanah dipantau. Walau bagaimanapun, RBF perlu dinilai berdasarkan kemungkinan ciri hidrologi dan hidrogeologi tapak setempat. Oleh itu, kajian ini dijalankan untuk mengisi jurang pengetahuan dalam menilai keupayaan gabungan air tanah dan air permukaan menggunakan sistem RBF dengan menggunakan beberapa kaedah penyelidikan. Oleh sebab itu, mengukur kecekapan RBF melibatkan data geofizik, analisis ayakan (saiz zarah), data ujian pengepaman, analisis isotop, statistik, pemodelan numerikal, dan data kualiti air. Parameter fizikokimia dan mikrobiologi air permukaan dan air tanah tempatan dianalisa sebelum dan semasa abstraksi air. Pengekstrakan air menunjukkan 5-98% penurunan dalam kekeruhan, serta pengurangan kepekatan HCO_3^-, Cl^-, SO_4^{2-}, NO^{3-}, Ca^{2+}, Al^{3+} berbanding dengan air permukaan. Di samping itu, jumlah E. coli, jumlah coliform dan Giardia berkurangan (99.9%). Walau bagaimanapun, sampel air dari salur ujian semasa pam menunjukkan kepekatan tinggi Fe^{2+} dan Mn2+. Dari kaedah pemodelan numerikal yang boleh dicadangkan untuk mencapai

penapisan dengan selamat dan mencapai kadar pengepaman yang ideal. Keputusan menunjukkan bahawa migrasi air sungai ke dalam akuifer biasanya lambat dan bergantung pada kadar pengepaman dan jarak dari telaga ke sungai. Kebanyakan air sungai tiba di telaga pada penghujung tempoh pengepaman 1 hingga 5 hari. Sepanjang tempoh pengepaman 9.7 hari, 33% air yang dipam dari telaga adalah air sungai berdasarkan jarak di 36 m dari sungai, dan 38% daripada air yang dipam dari jarak 18 m selama 4.6 hari adalah air sungai. Manakala, dalam mengkaji interaksi antara air permukaan dengan air tanah, isotop persekitaran seperti δ^2H dan $\delta^{18}O$ diberi keutamaan dalam kajian. Keputusan persampelan isotop dan persekitaran hidro-kimia telah menekankan bahawa kawasan berhampiran lembah sungai mempunyai hubungan dengan sungai dan air tanah dan secara aktif mengimbuh akuifer aluvial cetek berhampiran sungai, melalui kaedah RBF. Seterusnya, nilai kekonduksian hidraulik (K) dari sampel yang diambil dari tebing sungai dan dasar sungai, kemudiannya dikira dengan menggunakan kaedah persamaan empirikal, dari ujian pengepaman dan ujian kebolehtelapan menunjukkan bahawa nilai K adalah penting dalam proses penyumbatan dan halaju dan masa simpanan air tanah di dalam tanah. Malah, sampel air tanah dan air permukaan untuk tujuan analisis kualiti air minuman standard bagi musim basah dan kering telah dikumpulkan dan dianalisis untuk pelbagai parameter dan indeks air. Keputusan menunjukkan bahawa semua sampel air tanah dan air permukaan boleh dikategorikan sebagai kategori yang sangat baik dan baik. Sebagai kesimpulan dari penyelidikan ini, tebing sungai Malaysia mempunyai potensi yang lebih tinggi dan dapat menghasilkan air minuman yang boleh diminum dengan menggunakan sistem RBF tetapi pelbagai kaedah seperti geofizik, hidro-kimia, geokimia, pendekatan isotop yang stabil, ujian pam, alat statistik dan pemodelan numerikal mesti menjadi keutamaan untuk digunakan semasa kajian RBF. Dalam kajian ini juga, RBF ini boleh diterima sebagai penggunaan bersama air permukaan dan air tanah sebagai jaminan air negara yang boleh digunapakai semasa musim perubahan iklim.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Wan Nor Azmin Sulaiman, PhD
Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Mohammad Firuz Ramli, PhD
Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

Faradiella Mohd Kusin, PhD
Senior Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

Kamaruding Samuding, PhD
Environmental Division,
Malaysian Nuclear Agency
Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Name of Chairman of Supervisory Committee: ______________________________

Signature: ______________________________
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Signature: ______________________________
Name of Member of Supervisory Committee: ______________________________

Signature: ______________________________
Name of Member of Supervisory Committee: ______________________________

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a.g.l.	Above ground level
a.m.s.l.	Above mean sea level
BI	Bank Filtration
DA	Discriminant Analysis
DBPs	Disinfection by-product
DW	Test well
PW	Pumping Well
E. coli	Escherichia Coli
HAA	Haloacetic acid
MGD	Department of Minerals and Geoscience of Malaysia
DID	Department of Irrigation and Drainage
DSM	Department of Standard
K	Hydraulic Conductivity
KLIA	Kuala Lumpur International Airport
km	Kilometers
LUAS	Lembaga Urus Air Selangor
LK	lakes
m	meters
MAR	Managed Aquifer Recharge
MLD	Million liters per day
MMD	Malaysia Meteorological Department
MOH	Ministry of Health Malaysia
MPN	most-probable number
msl	mean sea level
MW	Monitoring well
MAE	mean absolute error
NRMS	normalized root mean square error
NAHRIM	National Hydraulic Research Institute of Malaysia
PCA	Principal Component
pH	Acidity/Alkalinity
Pintu	Gate
Q	Discharge/low flow
RBF	Riverbank filtration
RMS	root mean square
RW	River water
R&D	Research and development
Sungai	River
S_w	drawdown
T	Transmissivity
THM	Trihalomethane
TOC	Top of casing
VF	Varimax Factors
W_e	Well efficiency
WHO	World Health Organisation
DID	Department of Irrigation and Drainage
ENSO	El Nino-Southern Oscillation
FAO	Food and Agriculture Organization

IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
KeTTHA	Ministry of Energy, Green Technology and Water
KPKT	Ministry of Housing and Local Government/ Ministry of Urban Wellbeing, Housing and Local Government
KTAK	Ministry of Energy, Water and Communication
MOE	Ministry of Education
MOSTI	Ministry of Science, Technology and Technology and Innovation
NAHRIM	National Hydraulic Research Institute of Malaysia
NRE	Ministry of Natural Resources and Environment
RWH	Rain Water Harvesting
SIRIM	Standards and Industrial Research Institute of Malaysia
SPAN	National Water Services Commission
RBI	Riverbank Filtration
RBF	Riverbank Filtration

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Malaysia is located on the north of the equator, where its tropical climate supplies an average annual precipitation of 2940mm. The annual average rainfall differs between Peninsular (west) Malaysia (2490mm) and the less inhabited eastern states of Sarawak (3640mm) and Sabah (2560mm) on north Borneo. Rainfall is intense during the two monsoonal periods, between November-February and May-August. The total annual runoff is projected as 494 billion m^3, in contrast to the current water requirement of 14.7 billion m^3 and a project total requirement by 2050 of 18.2 billion m^3 (DID, 2010). The total obtainable water storage in Malaysia is 12 billion m^3, with net supplied by the direct river abstraction. The water supply is unequal in spite of huge water supply, neither spatially nor temporally. For instance, there have been cases of water shortage in the capital of Kuala Lumpur and neighboring Negeri Sembilan and Selangor states in 2014. This is mainly caused by absence of rainfall and low storage amount in fulfilling high demands. Moreover, “food basket” states, such as Kedah and Perlis in north east Peninsular Malaysia have also experienced water shortage issues which have affected the irrigation water supplies, and conflict with the provision of potable water supplies being transported from Kedah to Penang. Recently, the water supply condition in Malaysia had transformed from “one of relative abundance to one of relative scarcity” because of progressive pressure, water mismanagement, and climate change (Zakaria et al., 2013).

Henceforth, the Malaysian Government in February 2012 framed and sanctioned the National Water Resources Policy (NWRP). The policy comprehends a shift in attention on water as a reserve, which is different from previous observation of equating water management specially with the water supply industry. NWRP describes many strategies and action plans to address the issues and distresses for both instant and long-term to manage availability of water resources and demand in the country. Based on the aforementioned policy statement, NWRP offers definite guidelines and strategies with regard to water resources management to safeguard water security and sustainability. The security and sustainability of water resources shall be made as a national priority. This is crucial to ensure sufficient and safe water for all, through sustainable consumption, conservation and effective management of water resources facilitated by a mechanism of shared partnership containing the entire stakeholders. In the tropical nations, such as Malaysia, the focal source of dependable water supply is the river water where rainfall uninterruptedly replenish the river flow. Nevertheless, due to increased development and economic activities, the management of water resources can be very precarious owing to the upsurge in demand, as well as environmental degradation.

Importantly, pollution of rivers has caused the surface water inappropriate for treatment and in certain cases, has resulted in sudden increase in the treatment costs. Hence, there is a necessity to utilize groundwater as supplementary source of water supply to guarantee uncontaminated and dependable water supply solution without abandoning the resource potential of the polluted surface water. This can be accomplished via the conjunctive utilization between surfacewater and groundwater using Riverbank Filtration (RBF) scheme. Notably, river bank/bed filtration provides a virtuous practice to treat and protect the surface water, as well as groundwater. This is because; RBF utilizes the bed or a reservoir, lake or river and an adjacent sand and gravel aquifer as the natural filters. The technology can be utilized directly to the remaining surface water reservoirs, streams, lakes, and rivers, and now, it is frequently a guiding element in the hydrogeological examination of new source supplies. RBF is the influx of river water to the aquifer induced by a hydraulic gradient.

Collector wells or vertical wells are positioned on the banks in a definite distance from the river produce a pressure head change between the river and the aquifer, which prompts the water from the river to flow downward through the porous media into the pumping wells. By using the system of drinking water extraction, two distinct water resources are applied. Additionally, the surface water from the river percolates in the direction of the well; and the groundwater of the surrounding aquifer is applied (Schön, 2006). Majority of RBF systems are built in alluvial aquifers positioned alongside riverbanks. These aquifers contain many deposits ranging from sand, sand and gravel, large cobbles, and boulders. The ideal conditions usually comprise coarse-grained and permeable water-bearing deposits that are hydraulically connected with riverbed materials. These deposits are created in deep and wide valleys or in narrow and shallow valleys. RBF systems in deep and wide valleys may have a broader variety of choices as wells (vertical and horizontal collector wells) can be located at larger depths (which can offer greater capacities) and can be positioned further away from the river to rise the degree of filtration of the investigation on RBF has been scant in Malaysia. The growth may be delayed because of other selections, which could produce big projects, including inter basins water transfer from Pahang to Selangor. Therefore, such systems could not be applied in the future because more rivers are getting polluted. The RBF technology has been a routine practice in the Europe for more than 100 years, predominantly in nations including Switzerland, where 80% of the drinking water comes from RBF wells, 50 % in France, 48 % in Finland, 40 % in Hungary, 16 % in Germany, and 7 % in the Netherlands (Tufenkji et al., 2002). In Germany, for instance, 75 % of the city of Berlin relies on RBF, whereas in Düsseldorf, RBF has been applied since 1870 as the main drinking water supply (Schubert, 2002). In the United States of America (USA), however, this method has been applied for approximately half a century, particularly in the states of Ohio, Kentucky, Indiana, and Illinois, amongst others (Ray et al., 2002). Furthermore, lately RBF has been applied for drinking water supply in India (Sandhu et al., 2010), China, and South Korea (Ray, 2008).

1.2 Problem Statement and current challenges

The population of the state of Negeri Sembilan, Kedah, Penang and Selangor, one of most developed states in Malaysia, has now reached around 6 million as of 2010 (Department of Statistic Malaysia 2010). In Selangor, domestic demand grew at an average compounded rate of 5.9% from 1960 to 2006. Hence, for that year, the water used and demand was divided between the domestic and the non-domestic sectors by a ratio of 61 to 39 (Figure 1.1). Incidences of closure of water intakes have been due to river pollution, which had geared this study to find an alternative solution of being too dependent on surface water use. Since the last 20 years, there have been several occasions where the water intakes and the treatment plants have been closed as a result of serious river pollution. The closure of water intakes and water treatment plants has impact on water supply, and thus, on economic activities for industries and other sectors. The main sources of river water pollution are discharge of domestic sewage, pollutants from agro-based industries/farming, run-offs from earthworks and land clearing, and effluent discharge from manufacturing activities. The water operator incurred higher cost of water treatment; particularly in conventional sedimentation treatment plant, in which the high concentrated values of pollutants require higher volumes of chemicals. Pollution of river water has made river water unsuitable for source of raw water for treatment, and in certain cases, the treatment costs have raised unexpectedly. Constructing a new reservoir is one of the alternatives to increase the supply. However, it may damage the natural ecology and upset the balance in nature. Existing dams can no longer cope with such high demand, whereas building new dams will increase the government expenditure and affect the environment in long term. Thus, in order to supply safe drinking water and reduce disruption due to pollution, RBF is one of the best methods to provide water from both river and groundwater. According to Khairuddin and Abd Malek (2002), the sources of the Langat River pollution come from industrial discharge (58%), domestic sewage from treatment plants (28%), construction projects (12%), and pig farming. Research on the water contamination of the Langat River has been published by several authors, for instance, Zakaria and Mahat (2005) reported the sources and concentration of polycyclic aromatic hydrocarbon (PAHs) in the river sediment in the Langat Estuary and that the area was dominated by phylogenic sources, which meant that most of the PAH compounds came from the atmosphere, such as street dust. Farizawati et al. (2005) reported a study of *Cryptosporidium* and *Giardia* from cattle farms located near Langat and Semenyih Rivers that showed that out of 24 samples of water taken from the Semenyih river, 4.2% was positive for *Giardia* cysts with a concentration of 1.3 cysts/l, and 20.8% were positive with *Cryptosporidium* cysts with a range of 0.7–2.7 cysts/l. Liza (2010) identify the point source and non-point source pollutions during the base and storm flow events with secondary data from Department of Environment (DOE) from 2004 until 2008 and ranked according to statistical analysis as: E. coli (Non-Point Sources (NPS))> E. coli (Point Sources (PS)). TSS (NPS). COD (NPS)> NH_3-N (NPS)>BOD (NPS)>COD (PS)>TSS (PS)> NH_3-N (PS)>BOD (PS). The strong concentrations of BOD and COD are related to anthropogenic pollution sources from sewage treatment plants and industrial effluents. Lee et al. (2006) examined organochlorine insecticides from sediment, lake water and the Langat River. The study showed that endrin, chlordane, and aldrin were present in all water samples with concentrations for endrin: 0.02-0.21 µg/L, chlordane: 0.05-0.16 µg/L, and aldrin 0.03-0.13 µg/L. The source was from the river upstream flow through an area of oil palm plantation, where these insecticides might have been used for pest control in the past. Osman et al. (2012) identified sources of organic contaminants using chemometric techniques to classify the pollution sources in the Langat river basin based on the analyses of water and sediment samples collected from 24 stations to monitor 14 organic contaminants from PAHs, sterols, and pesticides groups. On the other hand, Othman and Gasim (2005) reported that heavy metal concentrations, such as mercury (Hg), cadmium (Cd), zinc (Zn), lead (Pb), copper (Cu), nickel (Ni), iron (Fe), cobalt (Co), and manganese (Mn) in the water of the Semenyih river watershed were determined in the water samples. Al-Odaini et al. (2011) monitored pharmaceuticals in the Langat River, which indicated that the samples collected from selected sampling stations along the Langat River were found to contain 15 out of the 19 targeted pharmaceuticals. In the past 20 years, judicial intervention and huge financial investment were undertaken to save the Langat River, but despite all attempts, contribution of contaminants from both the upstream of the Langat River and from the urbanization itself are still rising and need a comprehensive and strategic planning and management for the Langat River Basin. While, reports submitted by Binnie and Gourley (1961 and 1979) to the government of Negeri Sembilan had shown that the Linggi river is highly polluted and heavily-polluted requiring extensive treatment. In a report by DOE (2012) also classified that Linggi River was in the slightly polluted condition. The rapid urbanization and industrialization in and around the Linggi River Basin has resulted in increased water quality problems in the state (Nather & Firuza (2010)).

The water resources of the Muda River basin are in high demand for agriculture and water supply to towns and industry. Water from Muda Dam is also diverted to Pedu dam which has the biggest storage capacity at 1,080 MCM among the four dams. This arrangement is part of a comprehensive freshwater distribution system that covers the irrigation and potable water needs of Kedah and southern Perlis. The biggest user of water benefitting from this system is MADA granary area which has a size of 97,000 ha. The Muda River supplies about 32% of the MADA area irrigation needs. The Pulau Pinang granary area which stands at 9,800ha receives irrigation water directly from the lower part of the Muda River. The total irrigation water use is estimated at 3,800 MLD on average while potable water use is at 1,160 MLD. About 80% and 96% of public water supply need for Pulau Pinang and Kedah is derived from the Muda River respectively (Lee, 2009). According to National Water Resources Study (DID, 2010), the state of Kedah is currently in deficit for water based on available rainfall and consumptive demands. The shortfall is made up via the major water storages. Projected domestic demands are predicted to increase due to population growth while at the same time irrigation demands are predicted to decrease assuming improved future efficiencies.

1.3 Needs of the study

RBF has been demonstrated to be operative in eradicating majority of the impurities exist in the surface water. Evidence has indicated that RBF is a competent technique for substantial elimination of turbidity (Dash et al., 2008; Dillon et al., 2002; Wang et al., 1995), natural organic matter (NOM), pesticides, pharmaceuticals (Massmann et al., 2004; Verstraeten et al., 2002; Wang, 2002; Kühn and Müller, 2000), and salinity (Dillion et al., 2002). Moreover, taste and odour that cause compounds may not be eliminated from the surface water by conservative treatments technique (Worch et al., 2002). The prospective of RBF technique also shown to offer an important obstacle to microorganisms (Weiss et al., 2005; Gollnitz et al., 2003; Wang, 2002). In addition, RBF has shown to significantly decrease the manifestation of *Giardia* and *Crytosporidium* in drinking water applications when the flow path length and the filtration periods are adequate (Gollnitz et al., 2003). Over 100 years, the RBF technique has been applied for the Rhine, Elbe, and Danube rivers to produce drinking water. The Europeans have established effective elimination of particulate matter, manmade or natural organic, compounds, certain common bacteria, algae, disinfectant by-product precursors and an enormous quantities of chemicals and other micro-pollutants (Kühn and Müller, 2000; Grischek et al., 1998). Over the past years, majority of surface water in Malaysia are have been contaminated by numerous contaminants- domestic sewage, industrial waste, non-point sources, and discharge from agriculture activities. This has resulted in higher amount of chemicals usage in the treatment process, mostly in conventional sedimentation treatment plant. These chemicals are costly and are inappropriate for long-term treatment process as they are associated with severe health complications. Disinfection by-product (DBP) is among the key elements that have resulted in the establishment of new RBF treatment. The DBP can cause long-term illnesses like reproduction disorders, abortion and cancer. Thus, analysis on RBF is essential to establish a improved and sustainable treatment system for the water treatment industry in Malaysia. As this the first investigation on RBF study conducted using several techniques in Malaysia, the data and index value will offers insights for potential use of RBF as it is well-established method in the European nations. River-aquifer interactions are controlled by the unstable water level of the river. Majority of studies on river–aquifer interaction have concentrated on the discharge losses in streams owing to extraction of the groundwater by a pumping well (Hantush, 1965; Chen and Yin, 1999, 2001). Moreover, Chen (2001) highlighted that research on river discharge depletion must be extended by containing a determination of the subsequent features: the distance of the infiltrated river water that can travel into the aquifer during a pumping period, the travel time from the river–aquifer boundary to the pumping well, and the area of aquifer affected by the river water. A number of investigation have applied analytical solutions to deal with the movement of infiltrated river water inside a nearby aquifer (Chen, 2001; Chen and Yin, 2001). The current study applied numerical simulations using the groundwater flow code MODFLOW, a 3-D, cell-centred, finite difference, and saturated groundwater flow model developed by the USGS to commence particle-tracking simulations by means of MODPATH (a 3-D, particle-tracking code) established by the USGS. This model computes the paths for the imaginary particles of water moving via the simulated groundwater system. The simulations offer valuable info on significant factors relating to filtration including pumping rate and optimal distance between the riverbank and the production well. In the present study, travel periods, pathlines, and the influential zones of river water were decided between a river and an adjacent pumping well for seasonal groundwater extractions. These flow/transport parameters were assessed to describe the interactions amongst water in the river and the alluvial aquifer. Utilizations of such particle-tracking methods are essential in transport studies when conducting RBF to estimate the attenuation of pathogens during transport and artificial recharge. This is crucial to ensure that sufficient soil-retention time requirements are fulfilled for the eradicating human pathogens as the key objective of RBF operations.

1.4 Objectives of this study

The general objective of the current study is to assess the performance of RBF of an alluvium river bank.
Specific objectives:

i. To assess the prospective of Langat river Basin, Linggi river Basin and Muda river basin hydraulic properties, water quality and water quantity;
ii. To recognize sufficient storage of groundwater aquifer for water supply;
iii. To simulate the properties of well placement and pumping rate through modelling (MODFLOW);
iv. To evalute water interaction and groundwater recharge to appropriately manage aquifers;
v. To evaluate the important factor for establishing the index system of RBF.

1.5 Scope of the study

The study emphasize the features of RBF in the Langat river basin, Linggi river Basin and Muda river basin aquifer as the efficacy of RBF is determined by hydrogeological setting. The geology including hydrogeology characterisation is the vital component in assessing the probable of RBF positions. The comprehensive profiling of alluvial aquifers is a significant factor in choosing appropriate well sites and well design. The aquifer thickness, sediments, and ranges of alluvium are components of hydrogeology conditions that are essential in deciding the existing intake of water by RBF. Hydraulic conductivity of the aquifer and existing drawdown in the well are main constituents of the hydrogeology conditions to be applied for intake water from the well. The main elements for choosing and establishing appropriate RBF sites are the alluvial aquifer sediments and the thicknesses of the aquifer (Figure 1.2) and procedure for feasibility study of Riverbank Filtration (Figure 1.3). The scope of the procedure for feasibility study are displayed in Figure 1.4 encompassed soil examination at the suggested Horizontal Collector Wells W location (XC) @ 40 m depth; If geological profile is favourable, a test well will be built at XC added with 8 piezometers (X1-X8). Moreover, an aquifer test and water quality analysis as well as aquifer test analysis were performed. In addition, river depth profiles was determined at 9 sites. The current study also was particularly carried out to assess the performance of the method to treat polluted surface water. Furthermore, estimation of the effective rate of water abstraction was carried out for the examine location. Physicochemical and microbiological parameters of the local surface water bodies and groundwater were examined beforehand and throughout water abstraction as well as simultaneously to specify that a conjunctive use of surface and groundwater that could be improved via the RBF system for sustainability of water resource utilization in the examined location. The current study recognized the hydrochemistry effect to RBF in the study zone was analyzed to comprehend the interaction amongst surface and groundwater. This study is intended to deepen our understanding regarding the link and to persuade the water quality managers with regard to application of RBF technique to decrease specific parameters. The numerical models of the aquifer combined with groundwater flow system and the effect of groundwater pumping, and RBF operation on the influence of wells placement and pumping rate on flow paths, travel time, the size of the pumping and capture zone delineation and groundwater mixing in the pumping well that influenced the filtration process were safely attained during the pumping rate and established according to the information using the numerical modeling packages, MODFLOW and MODPATH. The developed model was applied for designing and to managing the RBF technique constituent. The models offered essential evidence required to establish a suitable water operator to construct, pumps and sample schedules for RBF practices and guarantee meeting sufficient soil retention times.

1.6 Limitation of the study

Hydrology characteristic of river, fluctuation in the river stage, changing in the hydraulic gradient from the river to the aquifer, clogging process, hydraulic conductivity of the alluvial deposits and dynamic is associated limitation of the study to remove certain bilological, inorganic and organic contaminants. As a pretreatment, these aspect should be taken account. Also space for research around riverbanks is limited to conduct systematic surveys according to the scope of the study. However, continuos of monitoring and observations and using various methods of the pilot sites could result in some what good interpretations. In study area, limitations of study could be financial constraints that limits the study of RBF systems.

1.7 Significance of the study

The implication of the study is threefold: First, the hydrogeological features of the study location (Langat River Basin, Linggi River Basin and Muda River Basin), which have not been demonstrated in several studies (Ngah, 1988; Tahir and Abdul Hamid, 2003; Japan International Cooperation Agency (JICA) and Department of Mineral and Geosciences Malaysia (DMGM), 2002; and Ismail, 2008). This is crucial to investigate the variations or uniformity relating to the hydrogeological features from the feature of groundwater occurrence and interaction between hydrogeological subsurface and surfacewater. Thus it is crucial to address these issues in order to deepen the understanding. The evaluation of the current hydrogeological characteristics of the Langat river basin, Linggi river basin and Muda river basin whereas the community is at its uttermost of socioeconomic prosperity is important fo RBF system study. The hydrogeological setting of the Langat river basin, Linggi river basin and Muda river basin may be dissimilar. Consequently, groundwater occurrences in the study location are addressed with regard to conjunctive use surfacewater and groundwater via Riverbank Filtration (RBF) to the origin of recharge either from natural precipitation on the study location or base flow from the River Basin.

Second, Langat river basin, Linggi river basin and Muda river basin as a main source of water resources. Therefore, the current research is linked to the government's initiative as described 11th Malaysia Plan to re-establish surfacewater groundwater resources as the conjunctive use via the RBF (GOM, 2010). The consumption of groundwater and surfacewater as the conjunctive utilized for water supply and feasibility study may encounter if the inadequate of groundwater and surfacewater extraction via RBF in consequence of aquifer feature is not addressed.

Third, three techniques, explicitly, geochemical, geophysical, and integrated techniques (Bear and Cheng, 2010), are generally applied to evaluate groundwater and surfacewater interaction according to RBF systems. The well-established technique that incorporates geophysical and geochemical techniques, which has not been formerly applied to examine the outcome of RBF systems. The current research also applied the statistical methodology to evaluate the importance and correlation of RBF controlling factors. The findings of the research considerably provide novel understanding with regard to RBF studies, particularly in Malaysia in the perspective of tropical environments.

1.8 Research Framework of the study

The research outline was adopted from preceding studies. The overall framework of the study is described in Figure 1.5.

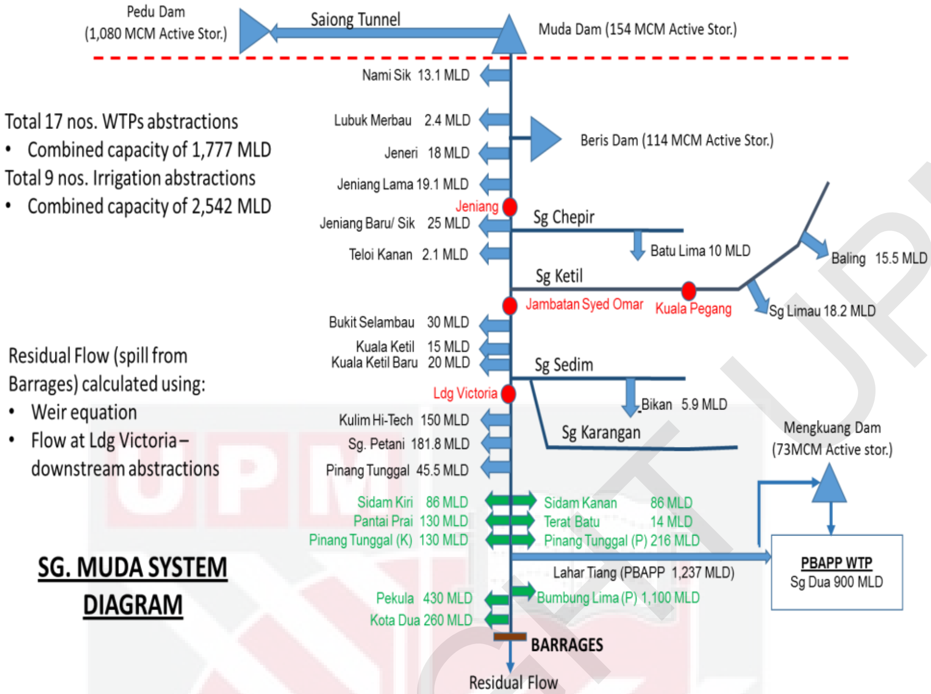

Figure 1.1:Existing of water use in Muda River Basin

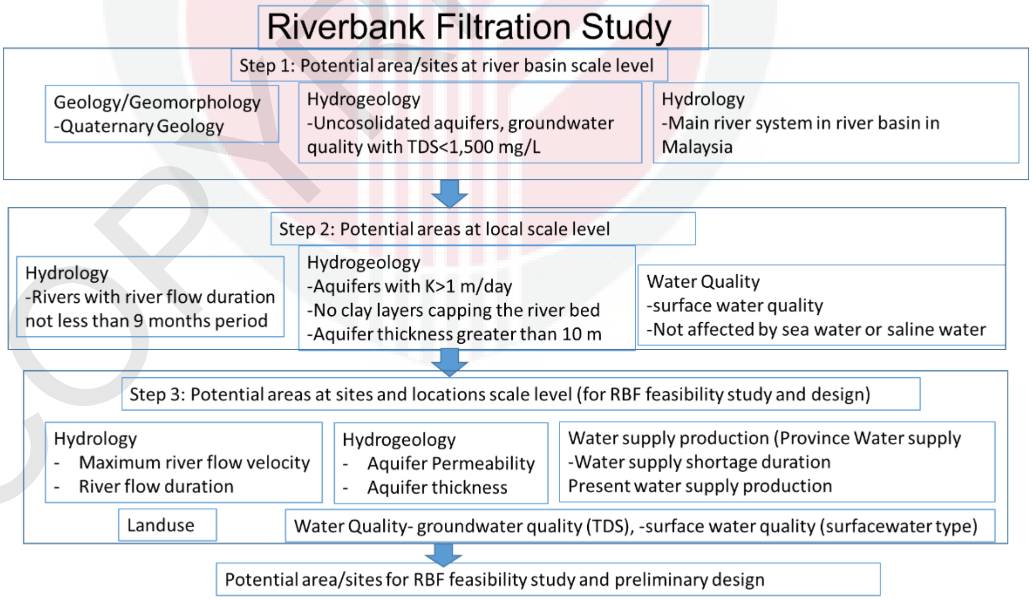

Figure 1.2: Frame work of riverbank filtration study for Langat, Linggi, and Muda river basin

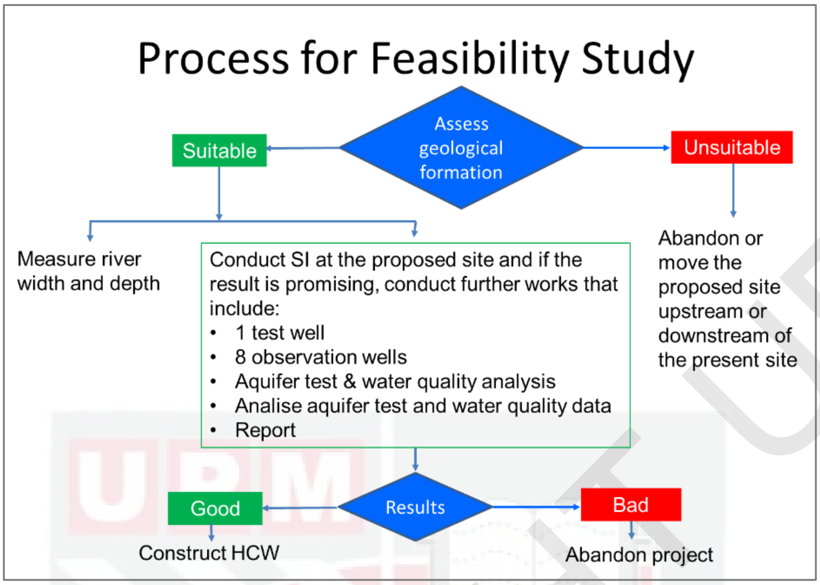

Figure 1.3: Summary of the process for feasibility study of Riverbank Filtration

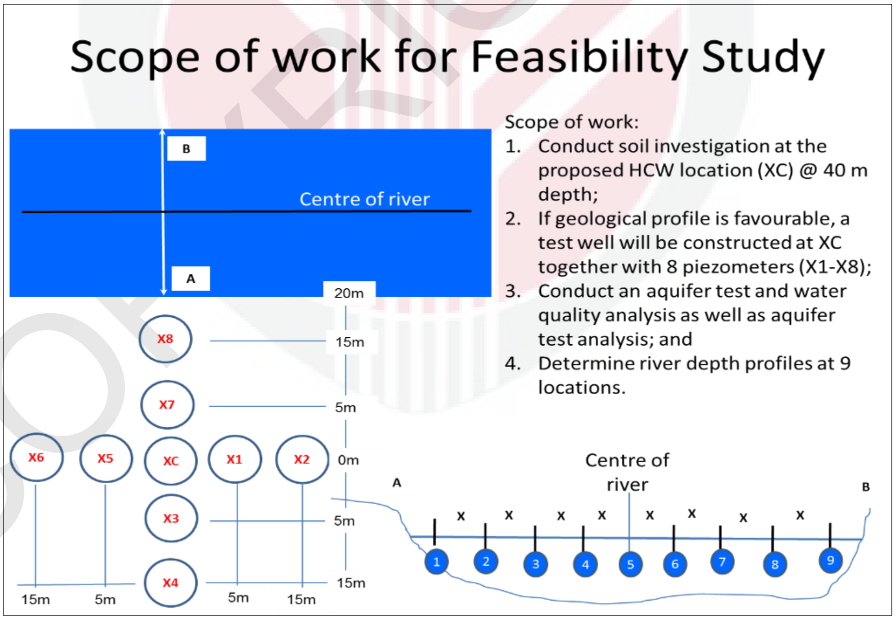

Figure 1.4: Scope of work for feasibility study tu fulfill the Riverbank filtration study

1.9 Outline of thesis

As constructing new-fangled dams and water intake is complex due to social, political and environmental issues. Therefore, efforts pertaining water resources preparation has been changed towards highlighting sustainable conjunctive application of RBF to complement surface water and to recharge the aquifer during episodes of any surplus inflow. RBF is progressively being refilled by filtration from river sources, is a resource incomparable in providing wealth. Thus, comprehensive investigation is required. In lack of any surface storage facilities, the only substitute storage is to permit bridging of dry periods. The study emphases on sustainable conjunctive application via RBF to increase the surface water combination with groundwater for irrigation as an extra source in Malaysia. The chapter (2) includes an extensive summary of literature review relating to the theory of RBF technology, its strengths and limits and the key issues with regard to surface water (Langat river. Linggi River and Muda River) issue and pollution. Previously, RBF was not utilized purposefully in Malaysia and the competences of RBF is largely unidentified. Chapter, 3 outlines a case study location, which was carried out in Peninsular Malaysian that evaluates the performance of the Riverbank Filtration (RBF) process in the metropolitan tropical areas of the nation. As such, a number of anthropogenic activities such as agricultural, industrial, and the municipal inflows have influenced the surface water.

The authors examined three distinct sites neighboring the Linggi River, Langat River, and the Muda River and their appropriateness was evaluated in building and establishing the RBF systems. The goal is to examine the designated operational RBF locations in the state (under study ever since 2012) and subsequently explain further prospective RBF locations reliant on the water concerns and the hydrogeological appropriateness, which is centered on the drilling at the prospective locations and at that time, observing the numerous water quality factors. In conclusion, the authors demonstrated that the designated locations neighboring the Linggi River, Langat River, and Muda River were appropriate for establishing RBF systems as they had an advanced prospective zone and were competent to produce clean drinking water for the consumers. Chapter 4, emphases on the surface–groundwater quality evaluated using multivariate statistical analyses centered on analytical quantitative data. Multivariate statistical analyses were applied, comprising discriminant analysis (DA) and principal component analysis (PCA). It can be applied to recognize surface water–groundwater interaction mechanisms and the influence of the sources of surface water (e.g. river and lake) pollution on groundwater quality in RBF sites by utilizing hydrochemical datasets. Chapter 5, emphases on groundwater tables predicting throughout applied RBF technique to recognize sufficient storage of groundwater aquifer for water supply reasons. This research demonstrates the establishment and utilization of artificial neural networks (ANNs) to forecast groundwater tables positioned in confined aquifer nearby to the Langat River. The findings demonstrate that precise estimates can be accomplished through time series 1-day in advance of forecasting groundwater table and the interaction between river and aquifer. The results of the research can be applied to support policy marker to manage groundwater resources via RBF technique.

Chapter 6 describes a case study of the RBF methods, which assesses the properties of groundwater pumping and RBF operation on the installation of wells. This study also concludes the outcome of pumping rate on flow paths, travel time, the size of the pumping and capture zone delineation, and groundwater mixing in a pumping well in Jenderam Hilir, Malaysia. The recommended technique implements filtration carefully and accomplishes the ultimate pumping rate. Numerical modeling packages, MODFLOW and MODPATH (particle tracking) were utilized. Chapter 7 describe a precise estimation of groundwater recharge that is required to appropriately manage aquifers, particularly for RBF technique reasons. Learning the environmental isotopes such as (δ^2H, $\delta^{18}O$) are essential primary tools in investigating the interaction amongst the surface and the water. This research utilized isotopes to obtain an improved understanding of the water interactions in the River Basin. This is a suggestion of the filtration of river water into adjacent alluvial aquifers as an alternative of taking groundwater discharge on its way to the river. According to the environmental isotope sampling, it has been evidenced that the recharging of the alluvial aquifers by surface water occurs through bank filtration, and that the recharge that occurs throughout increased rainfall events gains more dominance when it is positioned further away from the river. This is valuable evidence in achieving further understanding of the degree and nature of hydrogeology procedures occurs at the river-aquifer interface and how they are linked to geochemical process and policies of water allocation. On the origin accessing the stream-aquifer interactions and RBF systems, it is very important to regulate the vertical riverbank and streambed hydraulic conductivity. In the chapter 8, the riverbank and streambed concentrated in this study are a riverbank and streambed layers of sediments. In the investigation, there were several tests applied to conclude riverbank and streambed vertical hydraulic conductivity like grain-size analysis, pumping test and in situ falling-head standpipe permeability tests. Overall, the findings revealed that the aquifer of the concentrated zone demonstrates the potential for RBF and have the probable to enhance the water quality and quantity is referable. Geochemical characteristic and water quality index of groundwater surface water were emphases in Chapter 9. This chapter assessed with regard to factors influencing surface water and groundwater quality via numerous indices. In this study, samples of groundwater and surface water of standard drinking water quality for both wet and dry seasons have been gathered. The samples have been assessed for numerous physicochemical parameters, together with: temperature, dissolved oxygen (DO), pH, electrical conductivity (EC), total dissolved solid (TDS), salinity, dissolved silica (SiO_2), ionic concentration of major cations (i.e. Ca^{2+}, Mg^{2+}, Na^+, K^+) and major anions (i.e. Cl^-, HCO_3^-, SO_4^{2-}, and NO_3^-, PO_4^{3-}), and trace elements (i.e. As, Fe_{Total}, Cr^{2+}, Cu_{Total}, Hg^{2+}, Mn_{Total}, Ni_{Total}, Pb_{Total}, Sb^{3+}, Se_{Total}, Sn^{4+}, and V^{4+}). Assessment sample quality for both sources for the aim of irrigation has also been carried out via several index techniques such as SP, SAR, PI, KI, MH, Salinity Hazard, RSC, Chloride and EC. Lastly, Chapter 10 presents the findings and the case studies.

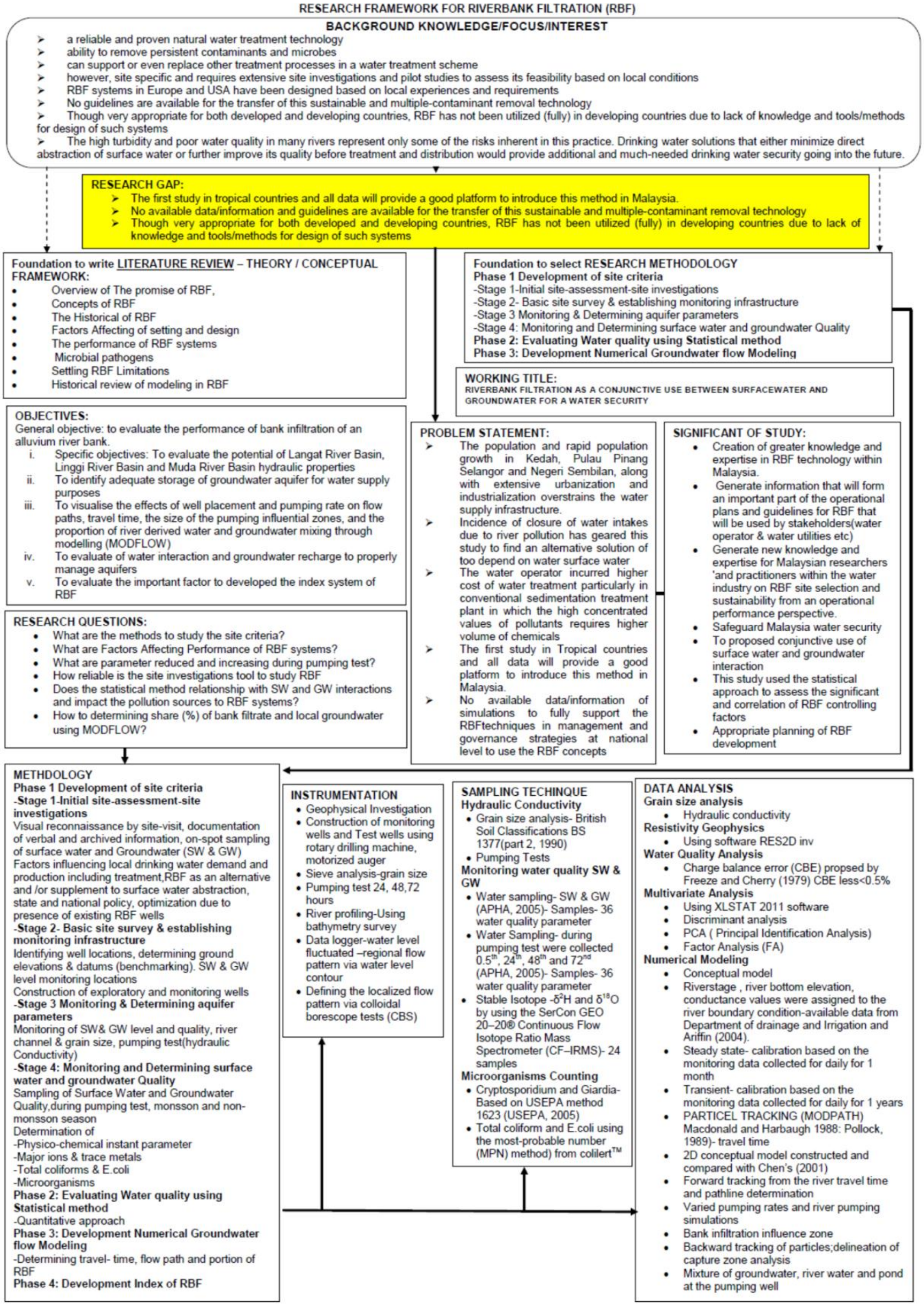

Figure 1.5: Framework for Riverbank filtration (RBF) study

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