SPATIAL AND TEMPORAL DISTRIBUTIONS OF WATER PHYSICOCHEMICAL, SEDIMENT QUALITY AND SEDIMENTATION IN SEMBRONG RESERVOIR

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Dan tiadalah duduk setempar bagi orang cerdik dan beradab itu dianggap sebagai rehat,
Tinggalkanlah tanah air dan mengembaralah,
Berkelanalah,
Engkau akan dapat pengganti orang yang kamu tinggalkan,
Berusahalah,
Kerana keindahan hidup itu ada pada berpenat-penatan

Aku melihat air yang tenang bertakung,
Mencemar kandungannya sendiri,
Sekiranya ianya mengalir, ia akan baik,
Sekiranya tidak mengalir, ianya akan tercemar

Imam Syafie

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ABSTRACT

Understanding the characteristics of a reservoir ecosystem is crucial in water resources management. The aims of this study are to investigate the limnological characteristics and spatial physicochemical properties of water quality in the Sembrong Reservoir. This study includes investigation of spatial variability of sediment properties and the quality of bottom sediment and long term sedimentation rate in relation to land use change and major hydrology events. The data collection was carried out from November 2011 to January 2013. Vertical sampling of reservoir water was conducted and its physical properties were measured in situ. Water samples were also analysed in laboratory for Al, Fe, K, Na, Mg, Ca, Fe, Mn, Zn, Cu, As, Pb and Total Phosphorous. Stable isotopes (^{18}O and ^{2}H) were measured using SERCON GEO 20–20 Continuous Flow Isotope Ratio Mass Spectrometer (CF–IRMS). A total of nine sediment cores were analysed for fallout ^{210}Pb and ^{137}Cs radioisotopes activities by Gamma Spectrometer. Sediment samples were also analysed for Total Carbon and Total Nitrogen and grain size distribution. Polymictic pattern was observed in this reservoir, especially during wet months. Thermal stratification occurred at depths between 3m and 4 m. The occurrence of photosynthesis at depth less than 3m increased phytoplankton productions. Manganese (Mn) and iron (Fe) concentrations were subjected to geochemical processes, particularly redox reaction. The mean concentrations of heavy metals in the water column decreased in the following order: Fe > Mn > Zn > Cu > As > Pb. Based on Carlson's Trophic State the Sembrong Reservoir is classified as hypereutrophic. On the other hand, the heavy metal concentrations as determined by the Heavy Metal Evaluation Index (HEI) fall under slightly polluted to polluted. Factor analysis suggested that the heavy metals are originated from modern agricultural plots. Higher heavy metal contents were observed in the west wing. This could be associated with micronutrient fertilizer from oil palm plantation with remarkable increases in the Enrichment Factor and Geoaccumulation Index for Zn, Cu, and Mn. Sediment mixing and digenesis processes influenced the deposition of bottom sediment. Given the irregularities of ^{210}Pb, long-term sedimentation rates were calculated by dividing the sediment thickness over a period. Higher sedimentation rates were observed at cores S1 and S6A with sedimentation rates of 1.10 and 1.17 cm/year, respectively. Forest clearing for oil palm plantation, dam development, and modern agricultural activities play important roles in the spatial and temporal distributions of sediment and water quality. This study highlighted the importance of limnology in controlling the physical and chemical processes in a reservoir ecosystem. The physicochemical properties of sediment also significantly influence the quality of reservoir ecosystem. Therefore, a comprehensive management plan to preserve the reservoir ecosystems is needed to ensure the sustainability of water resources.

ABSTRAK

Pemahaman terhadap ciri-ciri ekosistem takungan adalah penting dalam pengurusan sumber air. Tujuan kajian ini dijalankan adalah untuk menyiasat ciri-ciri limnologi dan taburan ruang sifat fizikokimia kualiti air di Takungan Sembrong. Kajian ini termasuk penyiasatan terhadap keragaman ruang sifat sedimen, kualiti sedimen dasar dan perkaitan antara kadar sedimentasi dengan perubahan guna tanah dan peristiwa hidrologi. Pengumpulan data dijalankan dari November 2011 hingga Januari 2013. Persampelan secara menegak dilakukan ke atas air takungan dan ciri fizikalnya diukur dilapangan. Kandungan Al, Fe, K, Na, Mg, Ca, Fe, Mn, Zn, Cu, As, Pb dan Jumlah Forforus bagi sampel air telah dianalisis di dalam makmal. Kandungan isotop stabil (^{18}O dan ^{2}H) diukur dengan menggunakan SERCON GEO 20–20 Continuous Flow Isotope Ratio Mass Spectrometer (CF–IRMS). Sejumlah sembilan sedimen dasar dianalisis untuk menentukan kandungan guguran radioaktif ^{210}Pb dan ^{137}Cs dengan menggunakan Gamma Spectrometer. Kandungan Jumlah Carbon, Jumlah Nitrogen dan taburan saiz sedimen juga diukur. Corak polimitik telah dikesan terutamanya pada bulan-bulan yang lembap. Kejadian stratifikasi suhu berlaku pada kedalaman 3m dan 4m. Kadar fotosintesis yang lebih tinggi berlaku pada kedalaman kurang daripada 3m dan telah meningkatkan penghasilan fitoplankton. Kepekatan Mangan (Mn) dan Ferum (Fe) adalah bergantung kepada proses geokimia terutamanya tindak balas redoks. Purata kepekatan logam berat dalam air berkurangan mengikut urutan : Fe > Mn > Zn > Cu > As > Pb. Berdasarkan Kadar Tropik Carlson, takungan Sembrong diklasifikasikan sebagai hypereutrofik. Sebaliknya, Indeks Pentaksiran Logam Berat menunjukkan tahap pencemaran logam berat adalah berada pada kadar sedikit tercemar hingga ke tercemar. Analisis faktor menunjukkan sumber unsur logam berat adalah dari petak pertanian moden. Kandungan logam berat yang lebih tinggi telah dikesan disebelah barat. Keadaan ini dikaitkan dengan baja mikronutrien dari ladang kelapa sawit yang menunjukkan kenaikan ketara Faktor Pengayaan dan Indek Geoakumulasi bagi Zn, Cu dan Mn. Percampuran sedimen dan proses digenesis mempengaruhi pemendapan sedimen. Oleh kerana ketidakstabilan ^{210}Pb, kadar sedimentasi jangka masa panjang telah dikira dengan membahagikan ketebalan lapisan sedimen terhadap tempoh masa. Sampel sedimen S1 dan S6A menunjukkan kadar sedimentasi tertinggi dengan nilai sedimentasinya masing-masing adalah 1.10 dan 1.17 cm/tahun. Aktiviti pembersihan hutan bagi penanaman kelapa sawit, pembinaan empangan dan aktiviti pertanian moden memainkan peranan penting dalam menentukan taburan ruang dan masa bagi kualiti air dan sedimen. Kajian ini membuktikan kepentingan limnologi dalam menentukan proses fizikal dan kimia dalam ekosistem takungan. Sifat fizikokimia sedimen juga memainkan peranan dalam mempengaruhi kualiti ekosistem takungan. Oleh itu, pelan pengurusan komprehensif untuk memelihara ekosistem takungan diperlukan bagi memastikan kelestarian sumber air.

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Bq/kg	-	Becquerel per kilogram
^{137}Cs	-	Fallout Caesium-137 Radionuclide
^{12}C	-	Carbon - 12
^{13}C	-	Carbon - 13
^{14}N	-	Nitrogen - 14
^{15}N	-	Nitrogen - 15
^{17}O	-	Oxygen - 16
^{17}O	-	Oxygen - 17
^{18}O	-	Oxygen - 18
^{210}Pb	-	Fallout Lead-210 Radionuclide
^{1}H	-	Protium
^{2}H	-	Deuterium
^{3}H	-	Tritium
^{28}S	-	Sulphur - 28
^{33}S	-	Sulphur – 33
^{34}S	-	Sulphur – 34
^{36}S	-	Sulphur - 36
Al	-	Aluminium
As	-	Arsenic
Ca	-	Calcium

CIC	-	Constant initial concentration model
cm y^{-1}	-	Centimeter per Year
CRS	-	Constant rate of supply model
Cu	-	Copper
DGM	-	Dark Grey Mud
DGMO	-	High Organic Content
DGSO	-	Dark Grey Sandy Mud With High Organic Content
DO	-	Dissolved Oxygen
C	-	Conductivity
EF	-	Enrichment Factor
Fe	-	Iron
GIS	-	Geographical Information System
GIS	-	Geographical Information System
HCl^{-1}	-	Chloride Acid
HEI	-	Heavy Metal Evaluation Index
HF^{-1}	-	Fluoride Acid
HNO_3^{1-}	-	Nitrate Acid
IAEA	-	International Atomic Energy Agency
ICP-OES	-	Inductively Coupled Plasma Optic Emission Spectrometry
I_{geo}	-	Index of Geoaccumulation
ISQG	-	Interim Fresh Water Sediment Quality
K	-	Potassium
LGM	-	Light Grey Mud
Mg	-	Magnesium
mg kg^{-1}	-	Milligram per Kilogram
mg l^{-1}	-	Milligram per Litre
Mn	-	Manganese

Na	-	Sodium
Ni	-	Nikel
Pb	-	Lead
QA/QC	-	Quality Assurance and Quality Control
SEL	-	Severe Effect Level
SRM	-	Standard Reference Material
TC	-	Total Carbon
TDS	-	Total Dissolved Solid
TN	-	Total Nitrogen
TP	-	Total Phosphorous
TSI	-	Carlson Trophic Index
Zn	-	Zinc

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CHAPTER 1

INTRODUCTION

1.1 Water Resources

Fresh water bodies are important for sustaining ecosystem functions and for supplying water. In Malaysia, approximately 98% of water supply is obtained from fresh water systems mainly composed of rivers, reservoirs and lakes. The main sources of fresh water are rivers and stream, the supply of which comes from accumulated rainfall on hillsides, where water flows downhill into the river catchment. Being located in a tropical region, Malaysia receives a total of 990 billion m^3 of annual rainfall, 147 billion m^3 of which becomes surface runoff (Azhar, 2000).

Due to a rapid increase in fresh water demand, dams are constructed from time to time to store and regulate water availability. The main purposes of dams are for water supply, flood control, and hydropower generation. Dams are usually constructed across flowing rivers, thus forming a river valley and an artificial basin. Some large dams have inundated a large area of land.

However, dam construction and subsequent operation have resulted in short- and long-term environmental effects (Ghrefat and Yusuf, 2006, Sharip and Zakaria, 2007, Çevik et al., 2009, Rahaman and Ismail, 2010, Bibi et al., 2010, Zhao et al., 2012b, Diman and Tahir, 2012, Mann et al., 2013). The alteration of natural morphology for dam development modified the hydrology and physical condition of the river ecosystem, thus significantly affecting the hydrological regime and sediment transport (Abraham, 1998, Smith et al., 2000, Chen et al., 2007, Diman and Tahir, 2012). It consequently disrupted ecological balance, not only on-site, but also to downstream and whole catchment area (Sharip and Zakaria, 2007).

In Malaysia, 74 manmade reservoirs have been constructed mainly for water supply, and hydropower (Sharip and Zakaria, 2007). Among these reservoirs, 34 serve as water supply dams. The locations water supply dams in Peninsular Malaysia are shown in Figure 1.1.

1.2 Agricultural Sector in Malaysia

Globally, agro-ecosystems have become major human-dominated ecosystems (Eaton and Franson, 2005, Sun et al., 2013). A tropical climate provides favorable conditions for agricultural activities in Malaysia. Malaysia’s agricultural sector consists of oil palm cultivation, rubber, coconut, short-term crops, fruits, cocoa, vegetables, tobacco, and pepper. In the 1950s, agricultural sectors in Malaysia mainly focused on self-sufficiency food. However, since the 1980s, this strategy has changed toward export-oriented agricultural products.

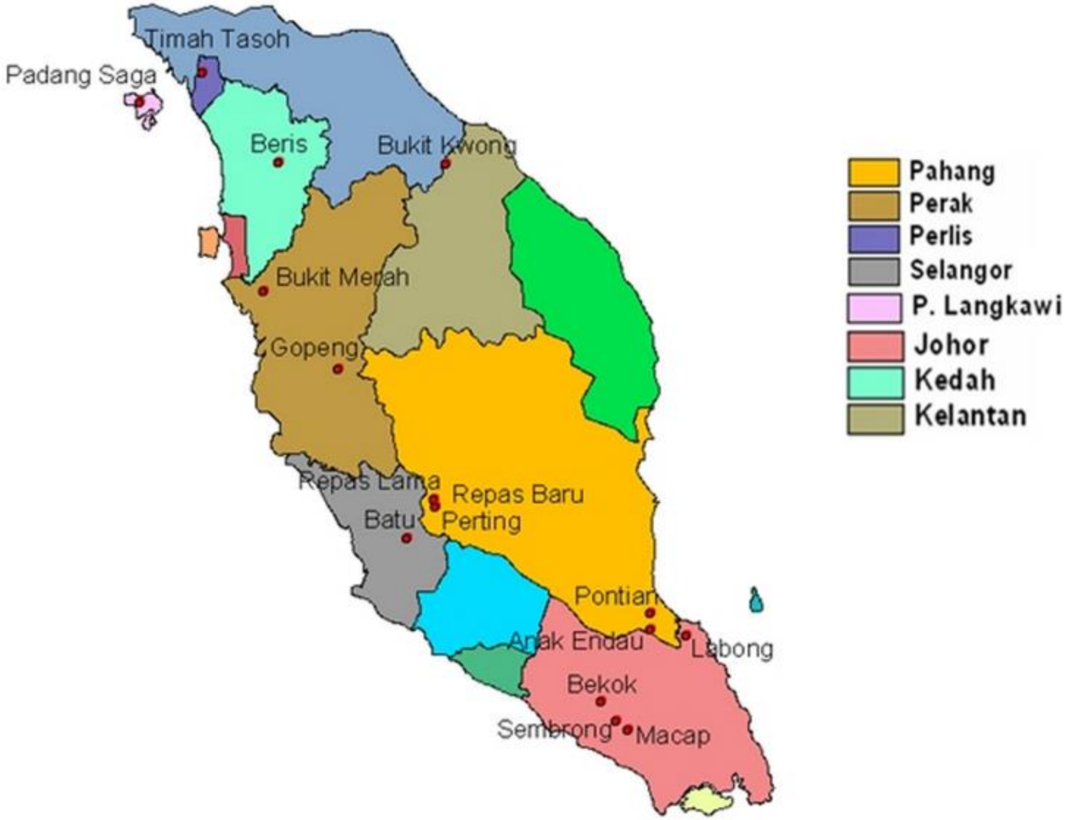

Figure 1.1 Distribution of water supply dams in Peninsular Malaysia (from Department of Irrigation and Drainage Malaysia, 2015)

In Malysia, a total of 5,291 million ha area was developed for agriculture (Ahmad, 2014) . In the early years of agricultural sector development, rubber was the main crop in Peninsular Malaysia. However, in the late 1990s, oil palm cultivation became the main sector. According to Sabri (2009), the area planted with oil palm continues to increase and has grown to six-fold over the last 30 years. Currently, oil palm plantations cover approximately 3,178,000 ha (Ahmad, 2014). To date, Malaysia has produced 18.79 million tons of crude palm oil, thus making the country the second largest producer after Indonesia (Sabri, 2009).

Despite the achievement in the agricultural industries in particular palm oil, the negative environmental impacts associated with agricultural practices are quite alarming. The agro-ecosystem in Malaysia has severely disturbed natural ecosystem. Land clearing and plantation development often lead to severe soil compaction, increase overland flow, surface runoff and erosion rates (Comte et al., 2012, Gharibreza et al., 2013b). In addition, to improve agricultural productivity, fertilizers have been widely used to replenish soil nutrients and to increase crop production. As evident from many part of the world, land clearing and fertilizer application have disrupted ecological balance as well as fresh water catchments (Chaplain et al., 2011, Costa, 2012, Sabri, 2009). Ecosystem degradation take various forms such as heavy metal pollution, eutrophication, sedimentation, and water quality impairment (refer Chapter 3).

1.3 Degradation of Fresh Water Resources

Water resources in Malaysia are confronted with several issues. The fundamental problems of water crisis begin at the catchment and reservoirs. Overall, previous studies of water resources in Malaysia concluded that unregulated human activities threaten water quality and quantity, thus making water unfit for consumption.

Population growth, expansion of urbanization, industrial, and agriculture activities, have led to rapid increase in water demands and exerting more on water resources.

Studies on water resources in Malaysia mostly focus on water quality, pollution status and sedimentation (Bakar et al., 2007, Ebrahimpour and Mushrifah, 2009, Ismail and Najib, 2011, Yap and Pang, 2011, Sani et al., 2012, Prasanna et al., 2012a, Akinbile et al., 2013). Sharip and Zakaria (2007) explained that cultural eutrophication is a major threat to water resources in Peninsular Malaysia. There are few water bodies that have been extensively studied in Malaysia which are Tasik Chini (Ebrahimpour and Mushrifah, 2009, Ahmad and Shuhaimi-Othman, 2010, Sharip et al., 2012), Tasik Bera (Gharibreza et al., 2013b, Gharibreza et al., 2013d), Timah Tasoh Reservoir (Bakar et al., 2007, Rahaman and Ismail, 2010), Bukit Merah Reservoir (Ismail and Najib, 2011, Sani et al., 2012, Akinbile et al., 2013) and Juru River Basin (Al-Shami et al., 2011). Overall, most of water bodies in Malaysia are severely affected by anthropogenic activities pressures.

Another common challenge in managing a reservoir in humid tropical areas is high rainfall intensity that leads to accelerated erosion rates (Bakar et al., 2007, Sharip and Zakaria, 2007, Mann et al., 2013, Gharibreza et al., 2013d). Increased sedimentation in a reservoir will often result in reduced reservoir surface area and depth, thus causing a decrease in water storage capacity. Moreover, recent studies indicated that sediment become an important contributor to non-point sources of pollution. The roles of sediment as a carrier of pathogens, nutrients, radioisotopes, heavy metals, and organic matter in an ecosystem have been identified to pose threats on water resources. Anthropogenic activities often accelerate the accumulation of metals and nutrients in sediments and potentially trigger non point source pollution. Overall, in Malaysia sediment is the main form of non-point sources of pollution and accounting for 56% of the total load (Azhar, 2000). Other sources of pollutants are human/animal waste, industrial waste, and others, which contribute 20%, 10%, and 14%, respectively.

1.4 Problem Statement

In Malaysia, untill now not many study has been conducted regarding sediment quality loading into lake ecosystem. This condition has made the conservation and maintenance of water resources difficult. Thus the following questions are asked:

i. What is the current status of fresh water body ecosystem?
ii. How human-dominated ecosystem change the natural processes in fresh water body ecosystem?
iii. What are the future trends of fresh water body ecosystem?

Sembrong Reservoir is one of the important ecosystems in Peninsular Malaysia. Since 1960's to recent, this reservoir has evolved from natural ecosystem to human-dominated ecosystem. The land use has changed extensively with the increment of agricultural activities covering 8% (1984) to 82% (2010) of the catchment. This reservoir could represent the impact of antrophogenic activities especially agricultural on water and sediment properties. In fact, the excessive growth of aquatic plants, especially water hyacinth *(Eichhornia crassipes)*, in this reservoir is a sign of nutrient enrichment and deteriorating of quality status (Figure 1.2). Yet, there is no detailed study been conducted on aquatic ecosystem status.

1.5 Objectives

Scientific information is needed to understand how human activities contribute to the chemical and physical processes in an aquatic ecosystem. A detailed study of water quality, sediment, and sedimentation in a reservoir are essential for evaluating the relationship among climatic-human-induced forces. Conservation and

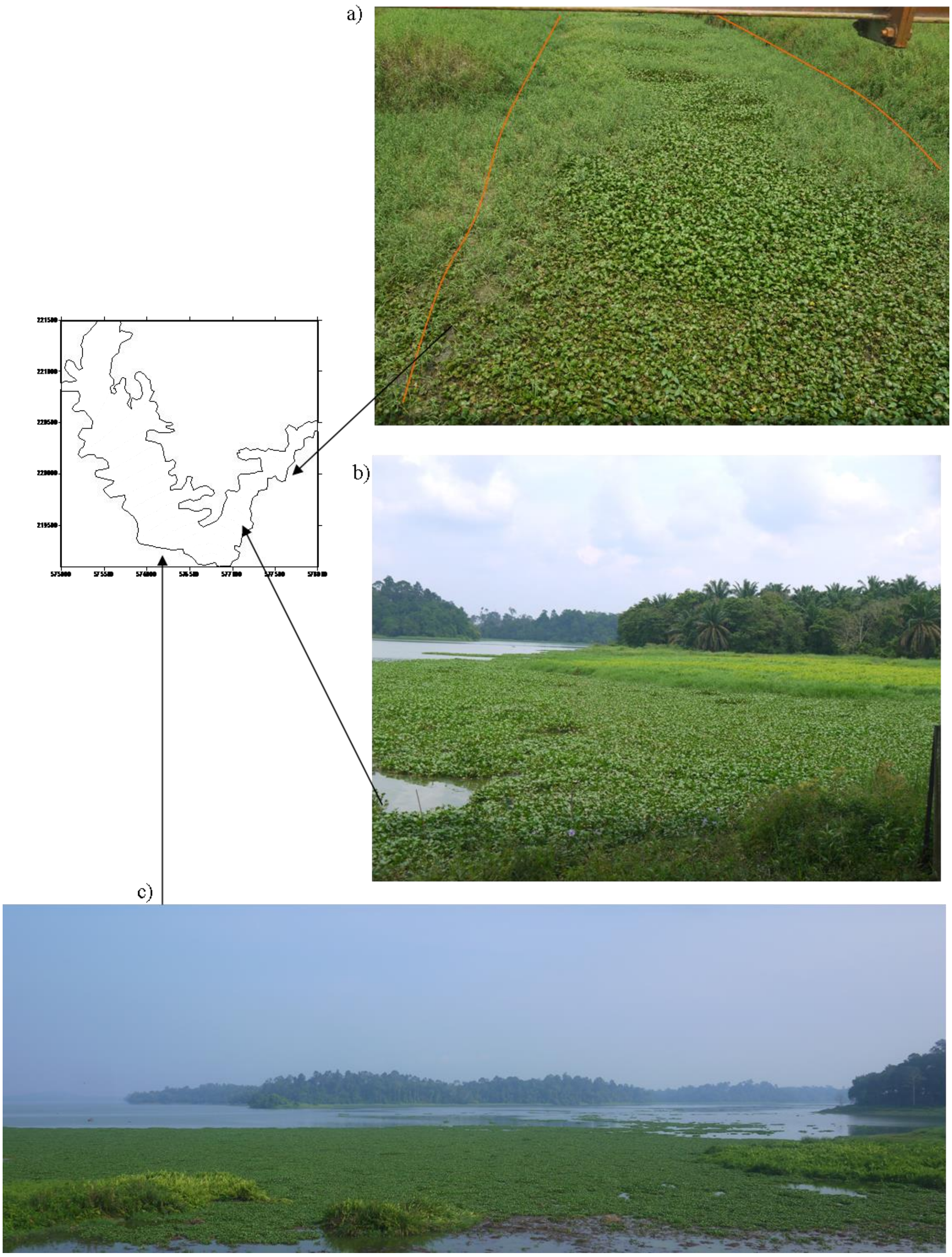

Figure 1.2 The presence of water hyacinth in Sembrong Reservoir in February 2012 and June 2012.

sound management of land use are needed to ensure the sustainability of a water body and the consumption of its resources.

The specific objectives of this study are as follows:

a) To characterise the limnology of the reservoir.
b) To investigate the spatial physicochemical properties of water quality in the reservoir.
c) To investigate the spatial variability of sediment properties and the quality of core bottom sediment.
d) To estimate the long term sedimentation rate in relation to land use change and major hydrologic events.

1.6 Scope of Research

Examining the complex interaction between land use, pollutant sources, and water quality, as well as how these factors affect ecosystem function are important to maintain fresh water quality. An interdisciplinary research is necessary to provide a scientific basis for formulating sustainable development. This study focuses on the physical and chemical properties of the water column to understand the limnology aspects of this reservoir. Vertical profiling is an alternative technique used to gain an in-depth understanding of the limnology and biogeochemical processes in the reservoir.

The chemical properties of bottom sediment are useful in understanding the impacts of land use changes on aquatic ecosystems. Meanwhile, assessing sediment geochronology with the use of radiometric dating techniques is useful for estimating long-term sedimentation rates. The radioisotope ^{210}Pb was used as a geochronometer in the sediment.

The general outline of this research is shown in Figure 1.3. The methodology of this study comprises three main sections which are i) Hydropgraphic Survey ii) Water column sampling and iii) Bottom sediment sampling. On the other hand, the expected outputs of this study will encompass water quality, limnology, sediment quality, sediment characteristics, and sedimentation rates. Bathymetry survey was conducted in November 2011 and water and sediment samples were collected in November to January 2013. A detailed description of the research methodologies will be presented in Chapter 3.

1.7 Research Significance

The development of appropriate water resources management and protection to reduce ecological health risks is necessary. Therefore, understanding the relationship between land use and ecosystem changes is important. Despite numerous studies on lake quality and sedimentation, other factors such as the influence of limnology, ecology and sediment non point sources pollution remains poorly understood, especially in Peninsular Malaysia. Gupta (2011) have argued that no two lakes are alike. Taking many factors into consideration, each of the physical, geomorphology and chemical factors could differ even within the same region.

Limnology characteristics in aquatic ecosystems are also important in controlling ecosystem health (Devi Prasad, 2012), because these characteristics control the physical and chemical dynamics of aquatic systems. As such, understanding the limnology is crucial to determine the responses of aquatic ecosystem. Therefore, evaluating the water column properties is a robust tool to determine the limnological characteristic. In addition, in order to determine the antrophogenic effects on the water body, the spatial pattern of chemical properties also assessed.

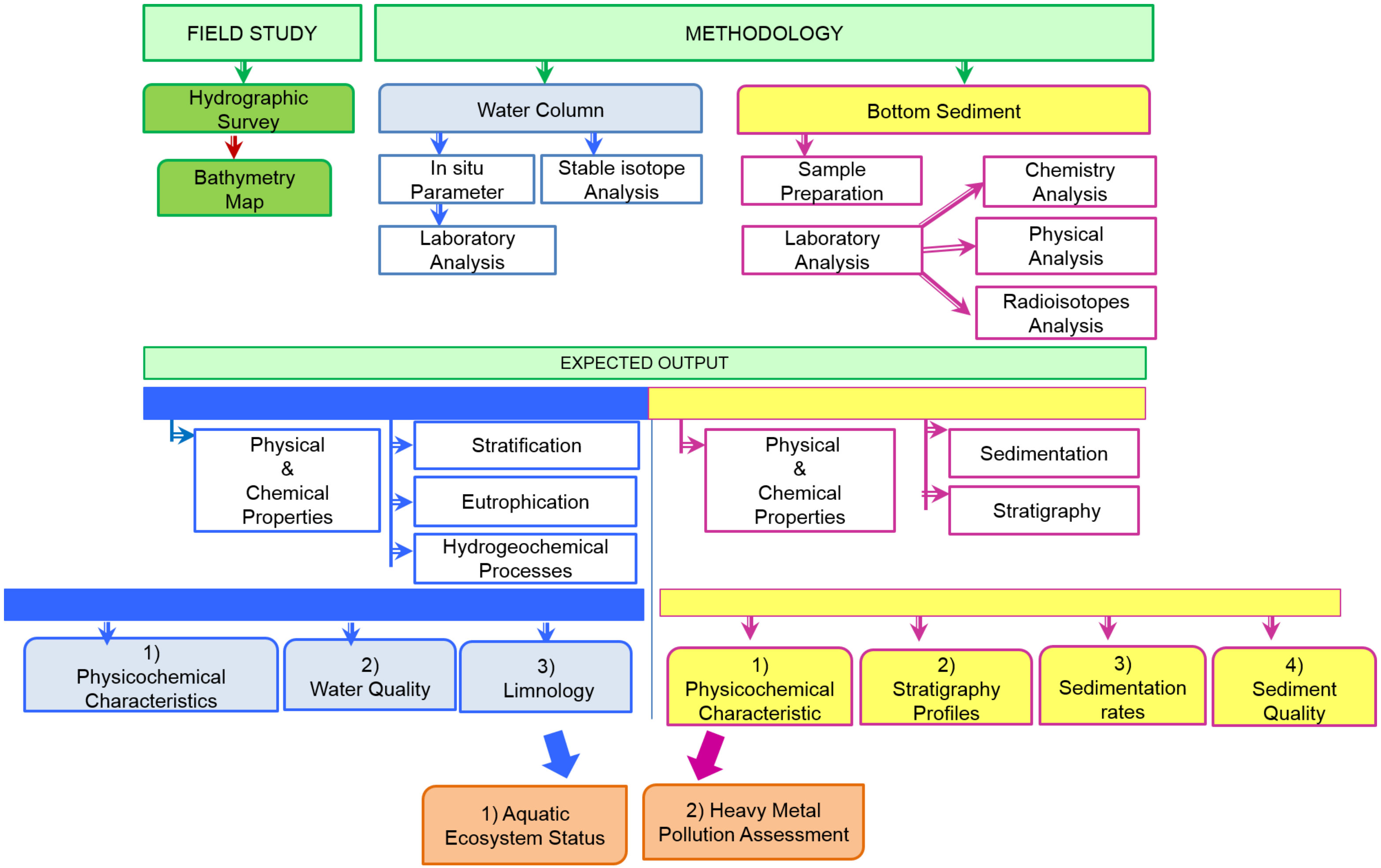

Figure 1.3 Research scope and procedures

Another motivation for this study is to understand the attribute of sediment acting as a non-point source contaminant carrier. As revealed by previous studies sediments in urban and industrial areas are contaminated by metals and organic chemicals. Thus posing risks to aquatic and human life (Huang et al., 2007, Bhuiyan et al., 2010b, Varol, 2011, Tao et al., 2012, Zhang et al., 2012, Akkoyunlu and Akiner, 2012, Liu et al., 2013a).

However, only a few researchers focused on this topic in Peninsular Malaysia. Therefore, monitoring the physicochemical properties of water column and bottom sediment are important to plan strategies for sediment and pollution control. A lack of scientific knowledge on the relationship between land use changes and aquatic ecosystem could hinder the effective management of water resources. An interdisciplinary approach is needed to provide reference data on water and sediment quality to formulate sustainable development and to preserve fresh water resources.

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