1. CHAPTER I: INTRODUCTION

This section explains that the thesis topic is concisely introduced and what the study will be addressed. This study is an original research project which was fulfilled in the most important natural habitat in Malaysia. This research entitled "Sedimentation Rates in Bera Lake and Soil Redistribution at its Catchment Using Radioisotopes". The topic has significantly represents the two main purposes and has highlighted the relevant methodology. Further, the topic has introduced a special sedimentary environment in Malaysia which the research was performed. It has appropriately demonstrated that research subject is an applied sedimentology field which will be supported by a high-tech method. In this section, issues in which the research is concerned, statement of the problems, aims and objective, research outline, and importance of selected study area are concisely introduced.

1.1. An Introduction of Study Area

Bera Lake is a lacustrine mire system located in the central part of Peninsular Malaysia, in the east-central State of Pahang. Bera Lake occupies 0.11 km^2 area at the most northern part of catchment, is the largest natural lake in Malaysia. The natural rainforest cover 593.1 km^2 in the Bera Lake catchment (BLC) prior to the Malaysian land development plans. The forest area decreased dramatically to 300.24 km^2 by the end of 1994. Permanent Forest Estate (PFE) in BLC was cited as the first RAMSAR site in Malaysia in November 1994, because of its biodiversity and ecological importance. The oil palm and rubber estates were established as a "Buffer Zone". In Malaysia any land use project beyond 500 ha should have an EIA (ECD, 2002b). However local residents

disregard this regulation by deforesting pockets of land in RAMSAR site since 1994 and leaving destructive effects on BLC ecosystems. Bera Lake wetlands and open waters made up 56.3 km^2 with a dendritic pattern and an elongate form. Their elevation is lower than 20 m and 2 degree slope, have remarkably occupied the low land areas which have geologically created 5,500 to 6,500 (BP) (Wüst et al., 2004).

The history of the study area could be divided in to two; prior and post 1950 or industrialization period. According to (Unpublished) Surut (1998) this area has been habitat of original Peninsular Malaysia indigenous (Orang Asli) people which historically living in the rainforest areas. Malaysian national plans were commenced since 1960 and Bera Lake and its catchment were recognized as one of the main states of land development projects.

The catchment area was significantly deforested since 1960 by FELDA, one of the main executive government agencies. Several important species of timbers were extensively harvested between 1960 and 1970. Then, five FELDA land development projects were fulfilled between 1970 and 1995. Land clearing is prohibited, 1994, after RAMSAR site citation. Simultaneously, wetlands and open waters have been being studied since 1961 in view of its scientific, anthropological, and economic importance. The biological aspects have been studied by several researchers including the Merton (1962), Furtado et al., (1982), Ikusima (1982), and Giesen (1998). The palynological history and evolution of Bera Lake was studied by Morley (1981). In addition to biological and anthropological studies, the geological setting and evolution of Bera lake basin, peat deposition, and new palynological aspects have been studied by Phillips and Bustin (1998), Wüst & Bustin (1999), and Wüst et al., (2001).

The research hypotheses assume that soil and nutrient loss rates, sedimentation rate in wetlands and open waters, Bera Lake water and sediment quality have been significantly affected by anthropogenic activities over the last decades. The hypotheses were tested by a comprehensive field surveys and experimental analyses to approve assumptions. As a result, Bera Lake and its catchment were selected to investigate sedimentary processes in order to cover existing gaps and effective contributions in the knowledge.

1.2. Issues in Which the Research is Concerned

The main issues in which the research project is concerned are:-

- Considerable soil erosion at BLC
- Severe sedimentation in Bera Lake
- Pollution of Bera Lake sediments

1.3. Problem Statement

Water and soil resources have been experiencing several stresses in Malaysia in the form of national agricultural scenarios. The first and second Malaya Plans (1956-1966) and the first Malaysian Agricultural Plan (1966-1970) have been supported by the government to promote the agriculture in the nation's economy (Henson, 1994). Efforts were made by the government to settle and cultivate huge tracts of undeveloped land through the FELDA schemes.

A widespread operations and extensive adverse consequences have been established in the study area during and post five documented deforestation and land development phases. FELDA has been the main implementing agency for land clearing and development in study area. Deforestation phases occurred between 1970 and 1975,

1976 and 1980, 1981 and 1985, 1986 and 1990, and then 1991 and 1995. Additionally, undocumented rubber plantations and timber harvesting have taken place during the first and second Malaya Plans (1956-1966). Consequently, extensive soil profile degradation caused considerable soil and nutrients loss, reduction of soil fertility, and creation of erosional features. In addition, considerable sediment transport and severe sedimentation have taken place and depth of the most important of natural lake and wetlands in Malaysia has significantly decreased. Heavy metals as product of deep chemical leaching has been released frequently in aquatic media, therefore, has resulted in water and sediment pollution, dramatic diminution of animals population particularly fishes, birds and relevant animals in Bera Wetlands and Lakes.

Adverse environmental impacts of a huge deforestation activities and ecological importance of the largest natural lake in Malaysia has led to an integrated ecosystem research on Bera Lake during 1970- 1974 at Pos (Fort) Iskander, within the framework of the International Biological scheme by the Joint Malaysian-Japanese. Further, the ecological of wetlands and open waters have been studied (1994-1998) by the joint Malaysian-Danish team (DANCED, 1998). Their researches focused mainly on the biological, coalification, and anthropological aspects. Assessment of literature review has remarkably highlighted a significant deficiency in the issues that the present research is concerned have never been properly studied and resolved. Additionally, previous studies in study area have not applied radioisotopes techniques and sediment quality guidelines to qualify adverse effects of land use changes.

Therefore, lack of scientific knowledge about current issues, the agricultural and ecological importance of the study area especially its wetlands and lakes, and the many

people who are effectively dependent upon the water and soil resources of the study area, brought great incentives to investigate the issues using advanced methods. This research will consider several issues in order to find scientific answers to the following questions:

- How much and where soil and nutrient resources of BLC have been degraded?
- What has been the fate of redistributed soils and nutrients in the catchment area?
- What are the current and historical variations in sedimentation rates in Bera Lake?
- What is the ecological risk of Bera Lake sediments?
- How sediment management practices could conserve soil and water resources of the study area?

Evidently, answers to those questions will reveal and resolve problems that the study area has been involved. Hypothesis will be tested by a comprehensive methodology in which the complete field surveying, detailed experimental analyzes, and an advanced modeling will be accomplished to achieve the objectives. Suggestions will be presented in order to minimize adverse environmental impacts of land use changes and conserve soil and water resources.

1.4. Aims and Objectives

The main aims and research objectives involve 1) Determination of the soil erosion rate in the catchment area, 2) Determination of the sedimentation rate in Bera Lake, and 3) Assessment of the Bera Lake sediment quality. The other aims were to 1) Investigate nutrient loss and its fate in the catchment area, 2) Develop the latest BLC land use map, 3) Develop the latest Bera Lake bathymetric map, 4) Measure the water and sediment discharge of Bera Lake. The other aims are mainly to support the main objectives and to cover existing gaps in fundamental and necessary data.

The overall purposes are appropriately suggested in order to explain issues in details and answers several questions about environmental impacts of anthropogenic activities within the study area. The significant contributions into the knowledge and achievement to the new findings are aims of this study in order to help the decision makers in terms of catchment management. The real reasons for severe reduction of area and depth at Bera Lake, reduction of fish population in the open waters, scarcity of emigrant birds and water quality degradation are the uncertainties for governmental agencies and decision makers.

In addition, BLC is at the threshold of replanting of a new generation of oil palm and rubber estates. Therefore, the research objectives will present real and quantitative guidelines for further land development projects to mitigate the adverse environmental impacts and to conserve soil and water resources in study area.

1.5. Outline of Research

General outline of this research would be followed chart (Fig. 1.1). Description of research stages in details would be presented in research methodology chapter.

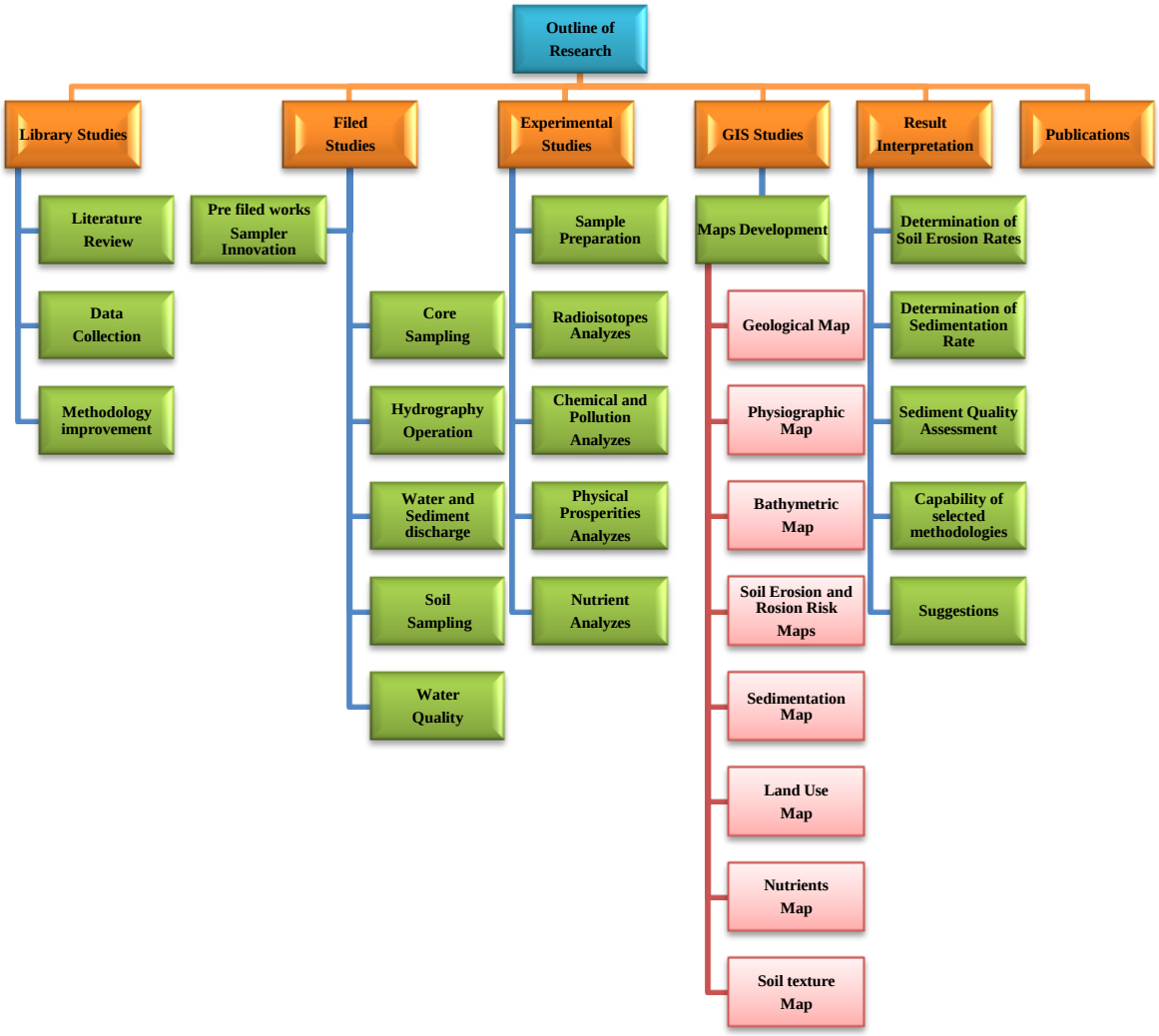

Figure 1.1: Research outline and procedures

2. Chapter II: REVIEW OF RELATED LITERATURE

2.1. Literature review

Literature review has been conducted according to research objectives which guided the routes of literature search and evaluation. The bibliography for this project includes 390 previous publications; involving 319 journal articles, 45 scientific reports, 19 conference papers, 30 books and book sections, 2 thesis dissertations, and 3 web pages, 212 which are cited in thesis. Endnote software version 4 was used to cite reference in text and to create the data bank for this research. Ninety five % of the reviewed literatures were collected as digital full text and copies of three of the useful books made. The digital and hardcopy data bases of the University of Malaya (UM) library, Nuclear Malaysia library, MPOB library, Malaysian Geological Survey library, and University of Malaya geology department library were the sources for collected literature.

Besides, MACRES, and Department of Survey and Mapping Malaysia, UM geology department have been sourced for preparing of satellite images (SPOT5, 2009), digital topographic maps (1:25000), and aerial photos, respectively.

Search of the UM data base Sciencedirect and internet on line data bases were the most important literature search engines. Radioisotope nature, radioisotopes and erosion, radioisotopes and sedimentation, sediment quality assessment, environmental impacts of land use change, watershed sediment management, sediment core sampling were the most common key word that were used for literature review. Although necessary and relevant literature was collected, complementary data as the latest supported articles also was collected in terms of data bank updating.

The most effective published references in terms of supporting the current research objectives are presented accordingly. The topic and themes of the reviewed literature can be classified as radionuclides nature and methodology, sedimentation in lakes and reservoirs, soil erosion, sediment quality evaluation, historical trends of pollution, oil palm plantations, watershed management, and relevant themes.

2.2. Nature of Radioisotopes

The nature and distribution of radioisotopes are discussed in Bujdosó (1997), Faure (1997), Robbins (1980), Jeter (1999), Benoit and Rozan, 2001, Smith (2001), and Smith et al., (2006). These references have supported this research in terms of understanding radionuclides concepts and their generations.

There is a long history into the limnological research around the world. Paleolimnological studies also have been performed especially to reconstruct history of a lake using radioisotopes (Benoit, 2001). A lake sediment column could reveal signature of several processes which have involved in sediment transport and distribution, nutrients cycle, and contamination within body of water. Besides, effects of worldwide parameter likes climate changes could be studied in a lake sediment profile. General issue with lakes is their reduction in capacity and trap efficiency due to sedimentation. This process has been repeated many times on the geological time scale, but recently caused many constraints to lake users. Sedimentation rates are measurable by traditional and new methods as hydrographic maps, *in-situ* surveying and physical measurements, and using isotopes tracer (Routh et al., 2007).

Isotopes tracers and their relevant models were selected as the main tools in order to achieve research aims. Nucleons are the protons and neutrons which compose the nucleus of an atom. Normally the number of protons and neutrons in an atom are equal. However, sometimes the number of protons and neutrons differ from each other. Atoms with different numbers of protons and neutrons in the nucleus are referred to as being isotopes (IAEA, 2001). All the different combinations of unequal numbers of protons and neutrons are called nuclides. There are about 1,000 known nuclides. Of these, 25% are stable and 75% are unstable. An unstable isotope is one which seeks stability by giving off protons, neutrons, or electrons. A stable isotope does not seek stability by giving off protons, neutrons, or electrons. Ionizing radiation is produced by unstable atoms. Unstable atoms differ from stable atoms because they have an excess energy or mass or both. There are three different types of atomic radiation alpha (α), beta (β), and gamma (γ) (Fig. 2.1).

On 16 July 1945 at 1230 Greenwich Civil Time, nuclear weapon testing was started resulting in the release of ^{137}Cs and other radioactive nuclides into the environment (Ritchie and Ritchie, 2005). Over the last 50 years after the first atomic weapon test, many studies have been published on the application of radionuclides to study soil erosion and the subsequent redeposition of the eroded particles on the landscape.

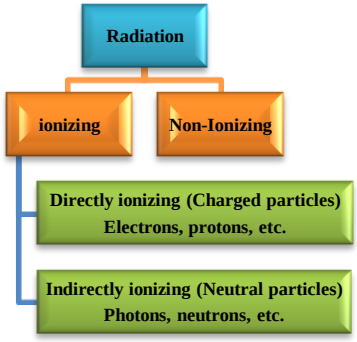

Figure 2.1: Types of radiation from unstable isotopes (IAEA, 2001)

Unstable isotopes or radioisotopes most commonly used in sedimentary processes and environmental research are presented in Table 1.2.

Table 2.1: Physical properties of radionuclides (IAEA, 2001)

Nuclide	Origin	Half-life	Time span	Energy
^{7}Be	Natural	53 d	6 months	477 keV
^{210}Pb	Natural	22 y	100 y	46 keV
^{134}Cs	Artificial	2 y	10 y	604 keV
^{137}Cs	Artificial	30 y	50 y	661 keV

According to Ritchie and Ritchie (2005) more than 3000 articles and reports on the application of only ^{137}Cs in investigating of sedimentary processes have been published. Overall review of radioisotopes literature could be divided to specific description and distribution, application in soil erosion, sediment transport, and estimate of sedimentation rate in lake and coastal environments, and finally its correlation with pollutions and nutrients in sediment column.

2.3. Analytical Methods

The fundamental analytical methods for calculating radionuclide inventories in environmental samples and sediment date have been identified in several references. The IAEA (1983) has been the foremost reference in this field which is supported by recent research works especially Ebaid and Khater (2006), IAEA (1983, 2005), Benoit and Rozan

(2001), Abraham (2000), Holmes (1998), and Hakanson et al., (1996). Ebaid and Khater (2006) has sophistically explained and compared three analytical methods (gamma and alpha spectrometry, and beta-counting) to detect fallout ^{137}Cs and ^{210}Pb radioisotopes inventory. Advantages and disadvantages of analytical methods and their capability to this project are to utilize gamma-spectrometry as the chosen analytical method for the research.

2.3.1. Radioisotopes Applications

Application of radionuclides in environmental studies especially estimations of soil erosion, sedimentation rates and historical detection of environmental changes have been studied by many researchers around the world. The literature reviewed has shown that IAEA (1983, 1995, 1998, 2001, and 2005) is the leader in introducing the radioisotopes capability in sediment studies.

2.3.1.1. Sedimentation Rate

Severe sedimentation at Bera Lake is the main research issue and application of radioisotopes is a perfect method to calculate historical deposition trend in this lake. One third of reviewed literature exemplified application of radioisotopes in the investigation of sedimentation rate. Although IAEA has been the former in the application of radioisotopes in order to estimate sedimentation rates, the most cited reference in this field is Appleby and Oldfield (1978) and their age calculation methods. In addition, Robbins (1980) and Walling (1999), Zapata (2000), Mabit et al., (2008) have presented fundamental articles in this field. For example, comparative advantages and limitations of the fallout ^{137}Cs, ^{210}Pb, and ^{7}Be radionuclides for assessing soil erosion and sedimentation have been presented by Mabit et al., (2008). Constant initial concentration model (CIC) (Robbins, 1980) and constant rate of supply model (CRS) (Appleby and Oldfield, 1978) are well known models

that have been cited in the published literature to calculate sediment age and sedimentation rate in lakes and other aquatic environments. Both models are based on activity of total ^{210}Pb (supported), ^{226}Ra, and ^{210}Pb excess (unsupported). Total activity of ^{210}Pb refers to both values of ^{226}Ra, and ^{210}Pb excess in soil or sediments.

Disequilibrium between ^{210}Pb and its parent isotope in the series, ^{226}Ra, arises through diffusion of the intermediate gaseous isotope ^{222}Rn (Begy, 2009). This gaseous phase decays to ^{210}Pb within 10 days of its creation from radon. The ^{210}Pb daughter removed from atmosphere by precipitation or dry fallout will be immediately attracted to soil on the earth's surface because of its high affinity to fine grained particles. In addition, ^{210}Pb which directly falls on lake or other water bodies could be detected in sediment column after deposition. The best sediment column age can be calculated accurately in stable basins with constant sediment supply and sedimentation. On the other hand, sedimentation rate in environments with certain environmental changes especially anthropogenic events and land use changes dominantly can be estimated by mentioned models. Smith (2001) believes validation of ^{210}Pb geochronology needed at least one independent tracer that separately provides an unambiguous time-stratigraphic horizon. In this project, ^{137}Cs is artificial radionuclide which is widely used as complementary tools to validate ^{210}Pb geochronology.

In addition to fundamental topics, numerous articles marked in literatures, discuses application of radioisotopes in estimating sedimentation rate in lakes. Some include Ariztegui (2010) , Flower et al., (2009), Hughes (2009), Sidle (2009), Putyrskaya (2007), Xu and Li (2007), Arnaud (2006), Bonotto & de Lima (2006), Mažeika (2005), McKee et al., (2005), Ruiz-Fernandez et al., (2005), Pfitzner (2004), Eriksson (2004), Abril (2003),

Lu (2004), Guevara (2002), and Benoit (2001). These references in fact are several case studies which have emphasized the importance of method and thus encouraged its use in the present project to estimate sedimentation rate in Bera Lake.

2.3.1.2. Soil Erosion

Another important theme that literature has been reviewed is the application of radioisotopes to estimate rate of soil loss. Ritchie and Ritchie (2005) stated that ^{137}Cs is the only technique that can be used to make actual measurements of soil loss and redeposition quickly and efficiently. Analytical methods and modeling of soil erosion estimation using ^{137}Cs have improved remarkably over the last four decades. According to Ritchie (2005), published papers on the ^{137}Cs technique commenced in 1961 and approached maximum in 1999 when new models were introduced by Walling and He (1999), Robbins (1980), and IAEA (1995). These fundamental researches were continued by Poreba (2006), and Mabit et al., (2008) who evaluated the models as well as the advantages and limitations of using ^{137}Cs and ^{210}Pb for assessing soil erosion.

^{137}Cs technique was used for estimating soil erosion around the world such as Garcia-Sanchez et al., (2009), Sidle (2009), Huh (2008), Jiyuan et al., (2008), Li, et al., (2007), Cha (2006), Rezzoug (2006), Stark (2006), Yunfeng et al., (2005), and Reguigui (2005).

There are several studies around the world which have used radioisotopes as tracers to detect historical events in watersheds and basins in order to find sources of contamination and to emphasis the role of soil and sediment grain size and organic matters in radioisotope behavior (Covay, 2001; Meyers & Lallier-vergés, 1999; He, 1996; Matsunaga, 1995).

2.3.2. Sediment Quality Assessment

Beside radioisotope analytical methods, published literature was reviewed also in order to identify sediment quality guidelines and evaluation methods. The profitable indices which are used remarkably in this research project were Xu (005), Caeiro (2005), CBSQG (2003), EPA (2001), and NOAA (2000). International standard guidelines motivated this research to evaluate the Bera Lake sediment quality in terms of relevant human health and aquatic life. Useful and elaborate sediment quality methods were initially presented by Müller (1979), Hakanson (1980, and 1994), Tomlinson (1980), Persaud (1993), Burton (1998), Pataki (1999), GIPME (1999), and Sutherland (2000). Hakanson (1980 and 1994) has introduced methodology which is widely used by many researchers around the world. This method evaluates sediment quality of lakes with given contamination factor, contamination degree, ecological risk for individual heavy metals, and ecological risk index for basin. Another functional factor is enrichment factor (GIPME, 1999; Sutherland, 2000) which would significantly reveal environmental events in sediment columns. As a result, the reviewed literatures have significantly improved current research in terms of analytical methods and sediment chronology models.

In addition, Olubunmi (2010), Yao-guo (2010), Aikpokpodion (2010), Ahmad (2009, 2010), Dauvalter (2009), Ebrahimpour (2009), Nayaka (2009), Sultan (2009), Yang et al (2009), Hai-Ao (2009), Tang et al., (2009), Honglei (2008), Kamala-Kannan et al., (2008), Mingbiao (2008), Rippey et al., (2008) are some of the latest studies which have frequently used analytical methods and sediment quality indices to find ecological risk assessment of individual heavy metals and degree of contamination of basin. These references show worldwide acceptance of the methodology that was decided to be used.

2.3.3. Historical Sediment Quality Assessment

Another theme in literature review was to recognize historical pollution trends in the lake sediment column using radioisotopes. Numerous studies such as Ariztegui (2010), Ciszewski et al., (2008), Fávaro et al., (2006, 2007), Xue & Xia (2007), Yang et al., (2006), Appleby (2004), and Yamamoto et al., (1998) have remarkably highlighted the capability of radioisotopes especially ^{210}Pb as the most useful tools for detection of historical change in the rate of contamination in the lake sediment profile. These references thus have given incentives to investigate environmental impacts of anthropogenic events at BLC on sediment pollution over the last few decades.

2.3.4. Historical Variation in Nutrient Content

Nutrients cycle in a soil profile has been widely studied around the world (Craft, 1998; Guo et al., 2003; Mabit, 2008b; Martinez, 2010). Nutrient content and their cycles have been repeatedly studied for their importance in sustainable agriculture, and tracing of anthropogenic effects at catchment area. Similar to soil profile, lake sediments have been widely investigated for historical variations in order to find environmental markers for tracing of eutrophication in watershed area with association of heavy metal contamination (Nagao et al., 1999; Hongve, 1995; Covay, 2001; Bonotto and de Lima, 2006; Routh et al., 2007; Alvarez-Iglesias, 2007; Rippey et al., 2008; Ueda, 2009; Flower et al., 2009).

Various studies on the importance of nutrient content in soils and sediments as indicator of soil erosion, sedimentation and eutrophication effects on the Peninsular Malaysia have been reviewed (Midmore, 1996; Phillips, 1998; Malmer, 1990; Wüst et al., 2003; Neergaard, 2008; Tanaka, 2009; Sultan, 2009). The visible gap in these studies is recognized as the geochronology of nutrient contents variations in a lake sediment column

using radioisotopes. For example, Neergaard et al., (2008) investigated soil erosion due to forest conversion to agriculture land using ^{137}Cs technique. Soil loss and erosion rate have not been analyzed in his research and agriculture lands were quite different with plantations in the Bera Lake catchment area. In addition, the author did not study geochronology of deposited sediments in sink area which induced from eroded lands. Present study is the foremost attempt in order to trace nutrient fate due to land use changes in one of the large catchment in Malaysia using ^{210}Pb and ^{137}Cs radioisotopes.

2.3.5. Watershed Management

Suggestion of a sediment management plan was marginally interests of this research in order to mitigate soil erosion and sediment delivery to the sink areas. For this purpose several watershed management plans were gathered and reviewed to provide a basis for the major sediment management scheme of study area. The oldest, and newest, management plans in Malaysia with regard to soil erosion and lake management were reported by Paramananthan (1984), and Sharip et al., (2010), respectively. Problems induced by land use change have been discussed in Paramanathan (1984) work. Sharip (2010) has emphasized the role of an integrated lake basin management plan at Chini Lake watershed area in terms of natural resources protection. Her management plan has been focused especially on Chini lake water quality as an ecological index, but the plan does not present solution to reduce soil loss in the catchment area and sedimentation rate in lake and thus mitigate Chini Lake water pollution. Other attempts for management of natural resources in Malaysia have been presented by Malmer (1990), Yusop (1990), Dorall (1997), Chee (1998), DANCED (1998), and Mutert (1999). These researches have studied different aspects of natural resources conservation. For example, Malmer (1990)

emphasized forestry treatments, while agronomic management practices have been presented by Mutret (1999), and Chee (1998). In addition, Dorall (1997) and DANCED (1998) introduced a GIS based and integrated management plan for BLC area for sustainable natural resources protection. These researches were the results of the AWB integrated management project at Bera Lake.

Some of management practices for adjoining a sustainable land use scheme and soil and lake conservation have been studied by Hui (2010), SPA (2010), Anton et al., (2007), and Sullivan (2004). Hui (2010) and Sullivan (2004) for instance have focused on sustainable soil management practices and control of sedimentation in sink areas. In addition, SPA (2010) is a sustainable planning regulation for assessing environmental impacts of land uses and relevant guidelines and policies.

Applications of radioisotopes in terms of soil protection and watershed management have been published by Jun and Zhiyun, (2007), IAEA (2001, and 2004). For example Jun and Zhiyun (2007) applied ^{137}Cs as a technique to quantify soil conservation capacities of different ecosystems. Detailed application of fallout ^{137}Cs and ^{210}Pb radionuclides, for sustainable watershed management were presented by IAEA (2001, 2004) in which several kinds of approaches for mitigating of soil erosion and sedimentation rates were listed.

2.4. Previous Studies of Bera Lake

Bera Lake has been studied since the commencement of the Second Malaya Plan (1961-1965) due to its multidisciplinary importance. Most of the previous works have been related to biological and ecological aspects of Bera Lake especially its flora and fauna. The

biology of Bera Lake was initially studied by University of Malaya and Botanic Garden of Singapore, published by Merton (1962). Between 1968 and 1972, a Japanese–Malaysian joint research group undertook an ecological study of Bera Lake (Furtado & Mori, 1982) that included information about plant decomposition (Sato et al., 1982), flora (Ikusima & Furtado, 1982), fauna (Mizuno et al., 1982) and fish ecology (Mizuno and Furtado, 1982). The evolution of Bera Lake has been studied by Morley (1981), who stated that the palynological evidence of Bera Lake Basin evaluation since 5300 BP. A semi-detailed soil characteristics and geology and mineral resources of east Bera Lake were studied by Tharamarajan (1980), and MacDonald (1970), respectively.

In November 1994, Malaysia became a contracting party to the Convention on Wetlands of International Importance (RAMSAR) Convention. The AWB initiated an integrated management project at Bera Lake. The project ended in June 1999 with publications of several reports, including anthropology (Surut, 1988), faunal and floral studies (Forest Research Institute of Malaysia, 1997; Giesen, 1998) and an ecological and geological report (Wüst & Bustin, 2001).

Phillips and Bustin (1998) have carried out a preliminary investigation onto the peat deposits. Geological evolution of Bera Lake and the complementary studies about coalification in wetlands and open waters have been studied by Wüst et al., (2002, 2003, 2004, and 2008). Besides, Wüst presented a new classification for organic-rich and peat deposits, and also explained the development of the interior peat-accumulating basin of tropical Bera Lake since Late Pleistocene and Holocene. The evolutional trend of Bera Lake was documented using three ^{14}C dating samples. Wüst and Bustin (2004) have stated that accumulation of organic matter occurred in local lakes during the LGM, but

widespread peat deposition did not start until 5300 BP when climatic changes led to the evolution of a wetland system. As a result, peat accumulation rates, ranging from 0.7 to 2.5 mm y^{-1}, are highest in *Pandanaceae* environments and lowest in high-ash swamp forests and environments dominated by *Cyperaceae*.

2.5. Conclusions

Overall conclusions from the literature review are summarized below:

- There is good fundamental literature on methodology and analytical methods in the work of Appleby and Oldfield (1978, 1997, 2000, 2001, 2003, and 2004), Walling and He (1994), Walling et al., (1999a, and 1999b), Robbins (1980), IAEA (1995), and Hakanson (1980, and 1994).
- The literature review has properly improved on presentation of results and mapping method as well as results interpretation.
- Previous works in study area indicate that medium-term sedimentation rates in Bera Lake using radioisotopes and advanced chronology models (CRS, and CIC) has never been applied.
- Another vivid gap was correlation between historical anthropogenic activities within the catchment area and medium-term variation of sedimentation rates, heavy metal influxes and physical and chemical properties of Bera Lake sediment profiles.
- Natural limits in Bera Lake and reviewed literature encouraged this research project to innovate a new core sampler in order to take an un-compacted and undisturbed sediment profile.

- Furthermore, previous works (Phillips, 1998; Wüst & Bustin, 2001) were mainly emphasized on coalification in wetlands of the study area, while the objective of this research is medium-term variation in nutrient contents using radioisotopes and estimation of land use changes impacts on nutrient cycle at catchment area.
- Direct measurement of Bera Lake bathymetric characters, water and sediment balance, and lake volume and trap efficiency has never been studied in previous works.
- There are few published practices for watershed and sediment management which used radioisotopes techniques.
- Reviewed literature, particularly previous works at Bera Lake have given incentive to perform detailed soil erosion and sedimentation rate investigation based on fallout ^{137}Cs and ^{210}Pb radionuclides. In addition, importance of Bera Lake and wetlands for ecological, tourism and livestock of the people have quite dependences to have encouraged us to investigate a comprehensive study on water quality and sediment quality assessment.
- Finally, sediment management plan is recognized as necessity scheme for Bera Lake area. Therefore, an integrated management plan based on published papers and new findings is suggested to achieve a sustainable land use scheme.