3. CHAPTER III: RESEARCH METHODOLOGY

3.1. Introduction

Materials and methods are the fundamental section of each research which outlines the research procedures. Hypothesis, objectives, and issues that the research is concerned have dictated the research methodology. Based on the questions that this study will be answered, research methodology reviewed in literatures. The main steps of methodology are literature review, field surveying, experimental analyzes, modeling, and interpretation. Detailed methods in terms of their procedures and outputs are appropriately presented in this chapter. The selected methods were strongly assumed to be appropriate methods to contribute in knowledge. The capability of each method to approach the objectives of this research was evaluated in the discussion sections.

3.2. Field Studies

Field observations are inevitable step of sedimentological and environmental studies. Comprehensive plan of field works and observations will guarantee results of any research. BLC, especially the main water body was the target of field works and observations in order to investigate research issues. Several field works were implemented to survey geological, stratigraphic and structural settings, soil and sediment core sampling, hydrographic operation, hydrological surveying, water elevation recording, water quality analyzing, and field validation of prepared maps. Each field work was essentially designed based on standard methods and according to Bera Lake situations. Details description of the applied methods (Radtke, 2005) is presented in the next sections.

3.2.1. Pre-field Works

Core sampler is the most important equipment for sedimentation rate study and environmental pollution (Burton, 1998). The capabilities of known sediment corers, such as the Russian type, KC sediment trap, Slide-hammer, Kajak-Brinkhurst, Phleger, Benthos, Alpine, Boomerang, and Ballchek were considered in order to select the best one that could be used in Bera Lake. These samplers are usually deployed using a winch that suspends the sampler about 5 m above the sediment to be sampled and allows the sampler to free fall, penetrating the sediment and forcing the material into the sample liner (Burton, 1998).

In an area like Bera Lake, which has an average depth of 2.5 m, the ability of a boat-launched sampler to reach the subsurface may be limited, and it may be more appropriate to use a modified device that can adjust to the boat's maneuvering in a shallow lake. In this study, two new kinds of core samplers, known as A Sediment Sampling Apparatus (ASSA) (A and B), were developed based on the sediment properties, depth, and boat availability at Bera Lake (Fig. 3.1a, b). The sampler was designed and developed at the Department of Mechanical Engineering, University of Malaya by the author. The novelty of the corer has been acknowledged and approved by the Center of Innovation and Commercialization of Malaysia via patent no. PI2011003971.

The sampler (ASSA) is classified as hand sampler or manually controlled. The sampler type A has main steel core barrel and interior transparent acrylic tube and the main transparent acrylic tube in type B with maximum 2 meter length. Both A and B types have a drop weight to serve as a hammer to drive the core tube into the sediment column easily. The samplers have additional drive rods that extend the core to collect samples of up to 10m depth. The primary object of the ASSA (Type B) is taking a plurality of undisturbed and un-compacted sediment samples simultaneously at one geographic sampling point in shallow lake, swamps, rivers, reservoirs, estuaries or coastal areas. The plurality of samples (Type B) allows implementation of various sediment tests with high accuracy. ASSA is portable, simple-to-operate, with high rate of coring success and low compaction. ASSA type B discloses that the sampling tube comprises a detachable stopper to prevent sediment from falling out when the apparatus is lifted from the ground. The present preferred embodiment of the invention consists of novel features and a combination of parts hereinafter fully illustrated in Figures 3.1a, b.

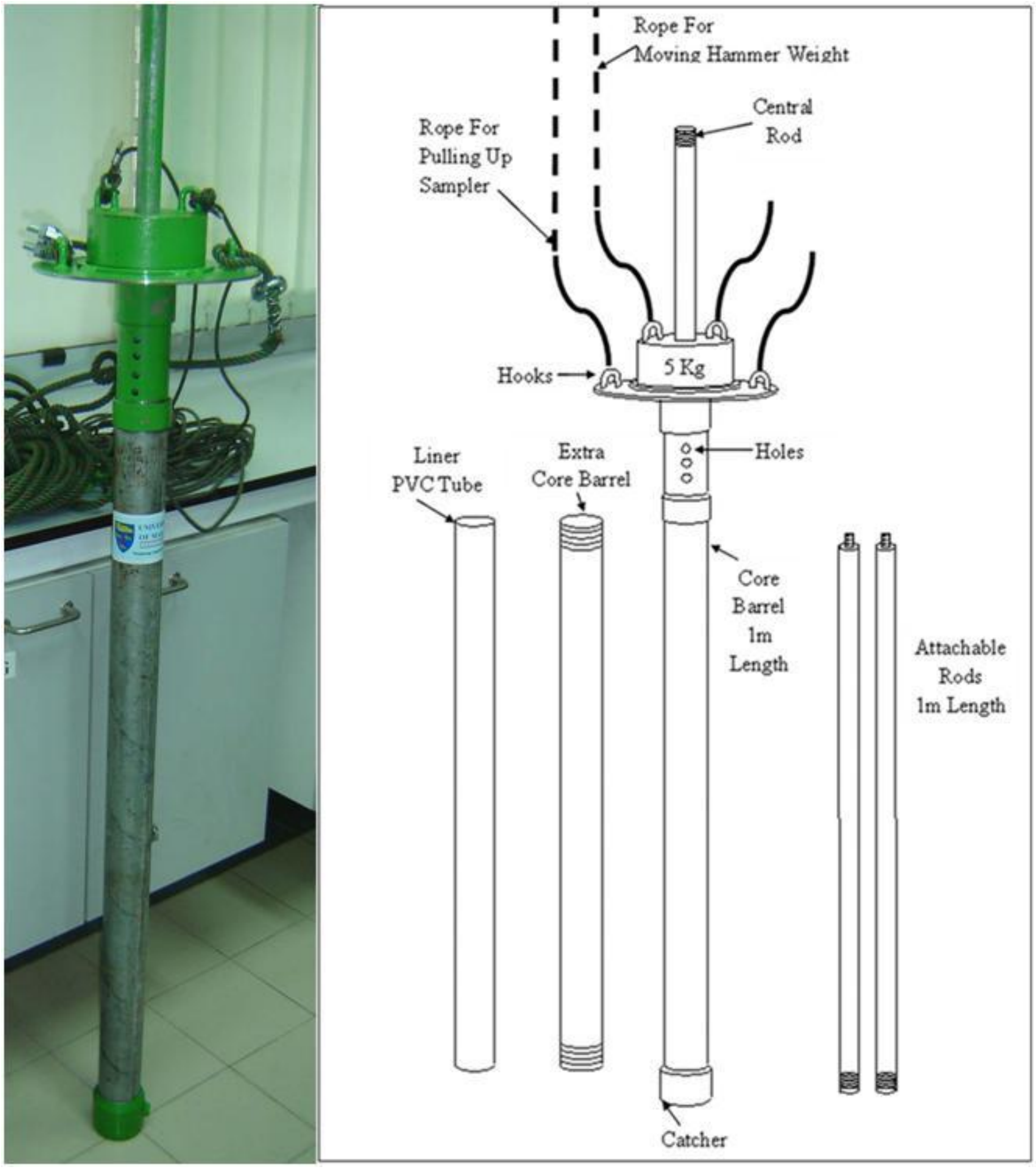

Figure 3.1a: The design and accessories of Core Sampler Type A

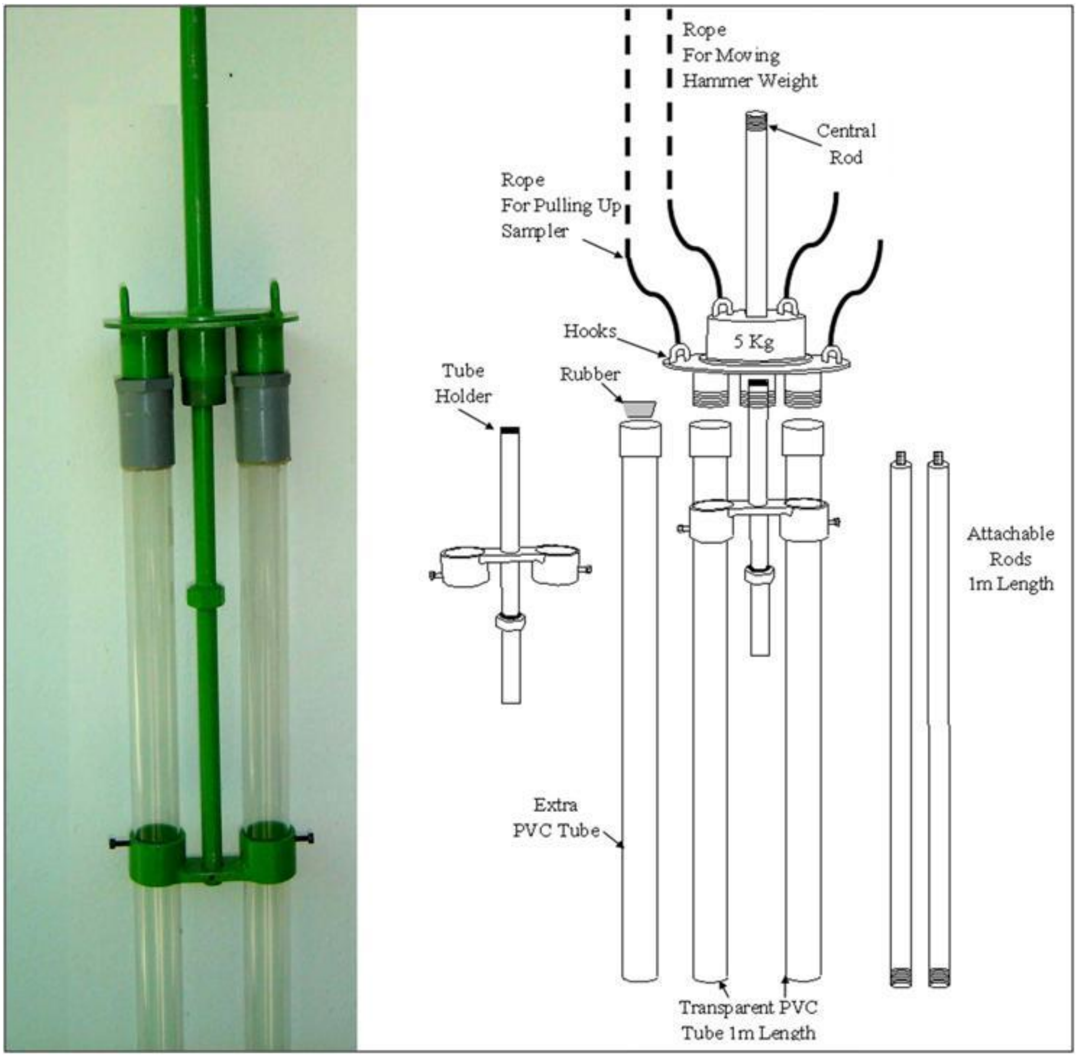

Figure 3-1b: The design and accessories of Core Sampler Type B

3.2.2. Core Sampling

Core sampling is the recommended method to be used to estimate sedimentation rate in the aquatic media, to measure accurate surficial sediment sampling depths, to assess the quality of sediment at various depths, to analyses geotechnical properties of sediment profile, and to analyses an oxygen-free environment (Radtke, 2005).

The U.S Geological Survey (USGS) bottom-material sampling manual (Radtke, 2005) was used for pre-field works, during sampling, and after field work procedures.

Radtke (2005) stated that selected sites for core sampling will affect the quality of the data collected. Experiences show that there is no formula to design a sediment sampling pattern which would be applicable to all sediment sampling programs (Mudroch & MacKnight, 1994).

Radtke (2005) has recommended applying statistical or deterministic methods to design the distribution pattern and number of sampling sites. Deterministic methods for selecting sampling sites for bottom material are based on professional judgment alone. Statistical methods for site selection sediment cores include stochastic random, stratified random, systematic regular, and fixed transect methods. Applications and limitations of selected statistical methods for select as sampling sites of bottom-material are presented below (Mudroch & Azcue, 1995).

1- Stochastic random method

- Commonly used in reconnaissance surveys where little is known about local conditions.
- The most unbiased method of site selection.
- Efficient in areas with homogeneous bottom material.
- Potentially ineffective in areas with heterogeneous bottom material.

2- Stratified random method

- Often permits elucidation of subtle but real differences.
- Requires knowledge of local conditions.

3- Systematic regular method

- Randomness achieved through selection of initial sampling site using a number chosen from a random numbers table or from electronically generated random numbers.
- Produces biased results.
- Fixed-transect method
- Sites not chosen randomly, therefore any inference is site specific, and areal conclusions may not be valid.

3.2.2.1. Sampling Strategy

Four pilot core samples were taken from different parts of Bera Lake to evaluate the homogeneity of Bera Lake sediment column or any variation in the strata thickness. The pilot core samples were taken based on stochastic random method. Overall analysis of sediment stratigraphic column showed five distinct layers along the depth profile of 0-100 cm which suggest illustrated conformity of deposition processes. Details of Bera Lake sediment stratigraphic is presented in the Section 4.9.1. Dendritic morphology of Bera Lake and stream pattern governs the hydrological circulation and sediment redistribution. Elongated morphology of Bera Lake and pockets of *Pandanus* plants in the lake has led to the core sampling pattern to be more deterministic. Pilot core sampling showed that sediment column has not been developed properly along the main water way, and therefore sampling was focused on distinct sub-basins.

Deterministic sampling method was applied after recognizing the different parts of Bera Lake in terms of sediment entry and departure points and sub-basins. Final location of core sampling was selected to include 10 core samples from different parts of Bera Lake

(Fig. 3.2). Sediment Cores 2, 3, 7, and 10 were collected from the south, Cores 4, 6, and 8 from the middle while Cores 1, 5, 9 from the north of Bera Lake. Core samples have mostly collected by UM sampler type B (Fig. 3.3) because of its better maneuvering and sediment core recovery. Sediment core sampling procedures are presented as follows:

1- The core tube was decontaminated.
2- Water depth was recorded by Echo sounder Garmin 400C
3- The core tube was attached to the UM sampler head.
4- The location of each coring station was determined by the GPS
5- The coring device was gradually lowered into the water.
6- The core was driven into the sediment, using drive rods, until allowable penetration level.
7- The filled core tube was retrieved slowly and steadily to avoid agitating the sample.
8- As the corer is lifted out of the water, a plug was immediately inserted into the bottom of the core tube to prevent sediment from slipping out.
9- The core was evaluated against the following acceptability criteria:
    - At least 5 cm of overlying water is present
    - The overlying water is not excessively turbid
    - The sediment surface is relatively undisturbed
    - The core thickness is representative for research objectives
10- If the core met the above acceptability criteria, the core was processed immediately by cutting the core from 10 cm of overlying water.
11- The characteristic of the core (date, time of collection, layers texture and composition) were recorded.

12- The cores were sealed and kept vertically to prevent from mixing

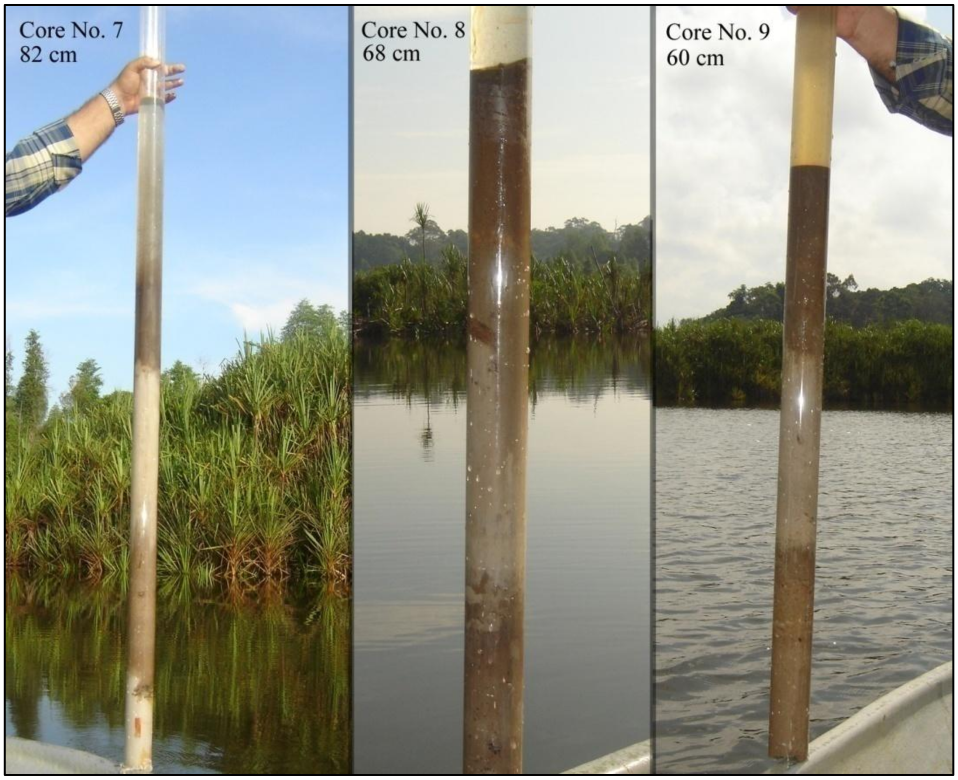

Figure 3.3: Some of core samples which were taken from Bera Lake

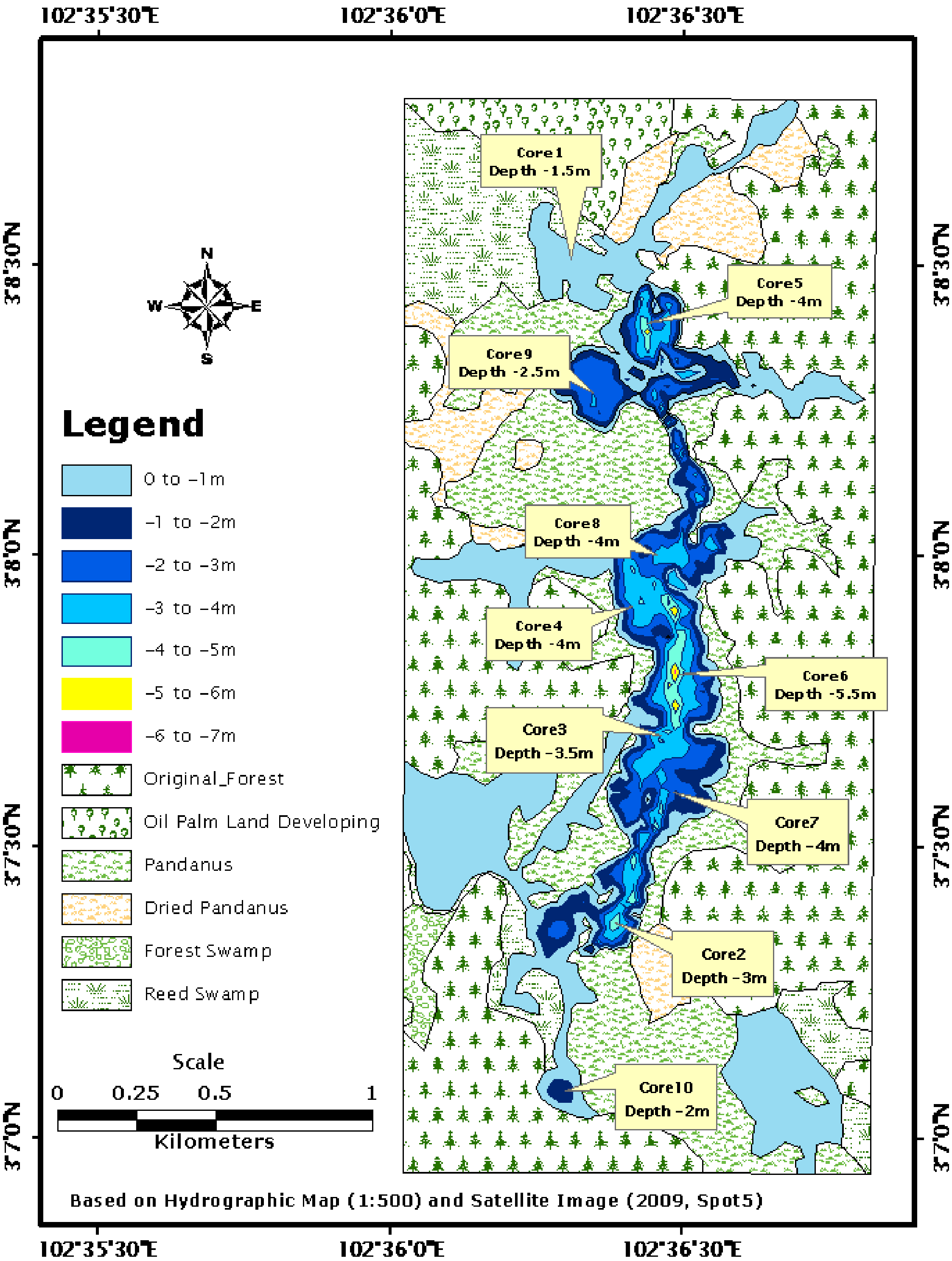

Figure 3.2: The bathymetric condition (m) and core sampling positions

3.2.3. Hydrographic Operation

Bathymetric map of water bodies is the prerequisite for hydrological and sedimentological studies. In addition, lake sedimentation surveys require a combination of local hydrographic and known benchmark point. Bed morphology is vital information for core sampling and evaluation of sedimentary processes of the basin. Trap efficiency of reservoirs and lakes is another important parameter that could be determined using bathymetric map.

Although Bera Lake was nominated as the first RAMSAR site in Malaysia, hydrographic survey has not been carried out prior to this research. As a result, a comprehensive hydrographic operation was designated to survey bed morphology in order to provide relevant information for further studies.

The most efficient horizontal positioning method is meter-level, code phase DGPS or private provider networks. Alternately, electronic total stations may be used for small lake or impoundment basins; however, this may require locating or establishing additional horizontal control points around the basin, adding considerable time and cost to the survey (Armstrong, 1998).

Kertau RSO Malay Meter Projection System has been used as horizontal positioning projection system. The best bathymetric scale of 1:500 or 20m x 20m network was applied to make best density of coverage in the hydrographic operation. A total of 1000 points were measured for horizontal positioning with additional 300 points of shorelines recorded. Vertical surveying in hydrographic operation was designed based on the capability of Echosounder Garmin 400C (Fig. 3.4). The depth accuracy of the

Echosounder is ±10 cm. Depth correlation which refers to the BM (benchmarks) datum, is a necessity procedure for preparing a seamless topographical and bathymetric map. This procedure correlates depth records with the nearest reported datum in the digital topographic maps of 1:25,000 scale (Series L8028).

Figure 3.4: Echosounder Garmin 400C and GPS used for hydrographic operation

3.2.4. Water and Sediment Discharge

Long and short term water and sediment monitoring provides valuable information about basin sedimentary regime. Although Bera Lake is the largest natural lake in Malaysia, its hydrological data has been main informational gap between previous studies. There is no hydrological gauge or station in BLC, the lack of data encouraged planning of the field works to a seasonal survey of water and sediment discharge into and from the

Bera Lake basin. Accordingly, three hydrological sections were selected based on two main water and sediment entry points and one main departure streams from Bera Lake.

The first and the most important inlet section was at south of Bera Lake (Fig 3.5) and another inlet section was on the Kelantong stream which ended to the lake at north-west of the basin. The outlet section was marked on the main channel which drains the lake before the junction with Bera River (Sungai Bera). Water and sediment discharge into and from the Bera Lake were measured in the two wet seasons (February and August, 2010) and one dry season (October, 2010), respectively.

Figure 3.5: Discharge measurement at the south inlet of Bera Lake

3.2.5. Soil Sampling

Soil sampling is a vital stage in soil erosion studies using ^{137}Cs and ^{210}Pb techniques. A review of sampling procedures for estimating soil erosion shows that the use of ^{137}Cs is a privileged sampling method Mabit (2008a). He also stated that this kind of sampling method is relatively simple and cost-effective and can be completed in a short time, depending on the sampling density and size of area. Site disturbing during sampling is minimal and will not interfere with seeding and cultivation operations. Furthermore, no disturbing of natural runoff and erosion processes might occur with the installation of bounded erosion plots.

It is evident that successful soil erosion estimation of a large catchment depends on the setting-up of a proper sampling strategy. For this study, land uses with the same cultivation date and geological setting (Fig. 3.6), low ^{137}Cs activity and accessibility by roads were the main factors that have affected the sampling pattern. Thirty-five bulk samples were taken to a depth of 25cm with a core sampler of 5cm diameter at sites of different land use (Fig. 3.7). Ten bulk core samples were also collected to a depth of 25cm in the bottom sediments of wetlands and open water. At each sampling site, six cores of 95.37cm^2 in area were collected in view of the low ^{137}Cs activity in tropical areas of Malaysia. The undisturbed forest in the RAMSAR site provided the best opportunity to find nine sites for reference samples. The reference sampling sites were chosen at open areas having low slope gradients (grass and bamboo lands) without erosion and sedimentation evidences. An incremental depth sampling carried out at 2cm intervals using a scrapper plate with a cutting edge and having a rectangular metal frame of 875 cm^2 in area. The sampling was carried out to a depth of 24cm where rock fragments were the main soil component and there was only a small clay fraction (Fig. 3.8).

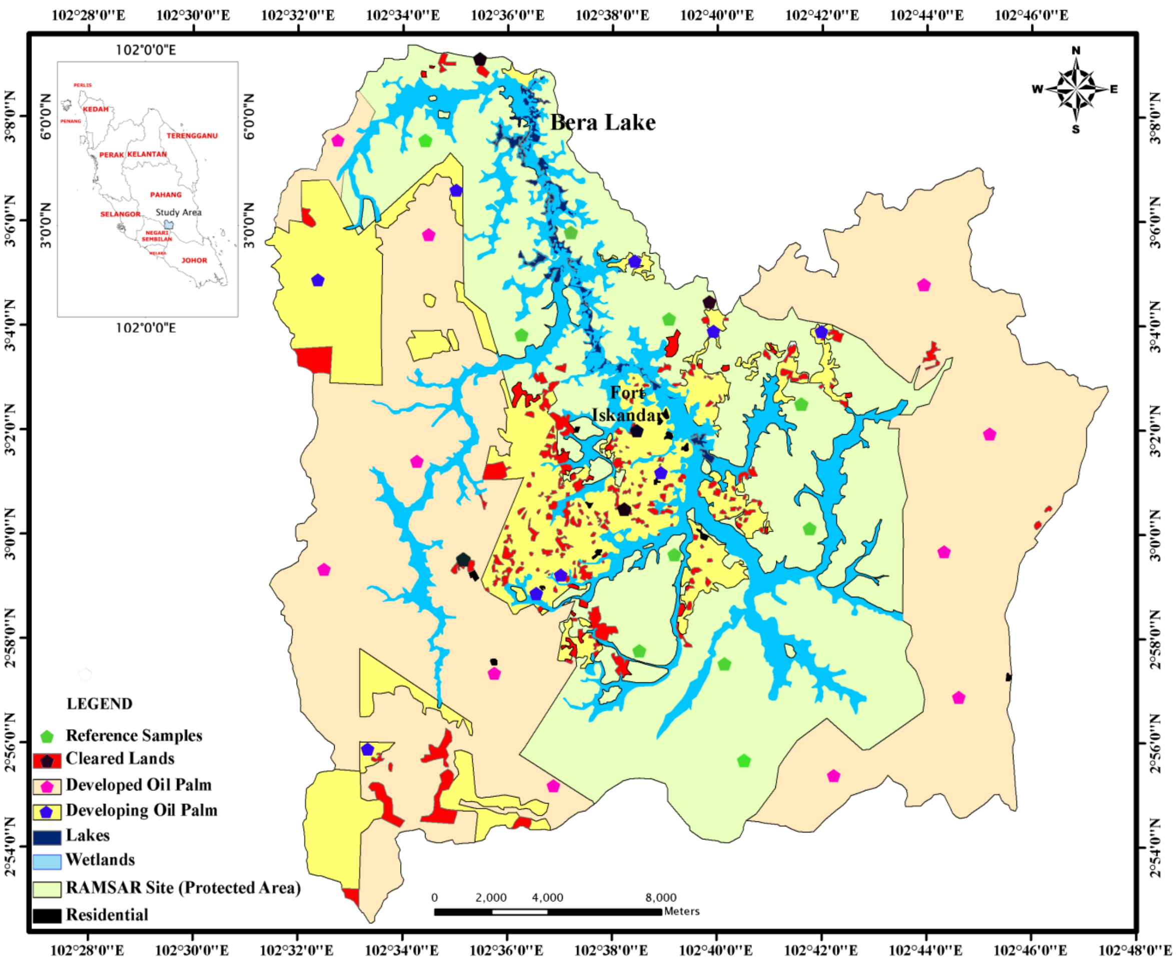

Figure 3.6: Soil sampling integrated with land use at the BLC

Figure 3.7: Sampling of soil using bulk core samplers

Figure 3.8: Utilizing scrapper plate to take reference soil samples

3.2.6. *In-situ* water Quality Recording

Evaluation of available water quality data of Bera Lake showed that most of published reports about water quality were back dated to 1972, by Malaysian-Japanese committee (IBP, 1972) prior to FELDA land development projects. Presently, the directory of RAMSAR site personnel collects water samples from 5 stations. However, attempts to access the data were not successful.

As a result, the lack of reliable water quality information especially on the effects of previous land development projects has complained a comprehensive water quality assessment comprehensively. Water quality survey was conducted in February, 2011 using calibrated fully automated Hydrolab DS 5 USA (Fig. 3.9). Eleven parameters include temperature (˚C), depth of sampling (m), salinity (ppt), Turbidity (NTU), TDS (mg l^{-1}), pH, NH_4^{+1}(mg l^{-1}), NO_3^{-2} (mg l^{-1}), Cl^- (mg l^{-1}), LDO (mg l^{-1}), DO (mg l^{-1}) and EC (mS cm^{-1}) were recorded at three levels of 0.2, 0.5, and 0.8 water depth. *In-situ* water quality was recorded in the 100 x 100 m network and was also based on the morphology of open waters.

3.3. Experimental Studies

Experimental analysis is an inevitable procedure in the application of radioisotopes for soil erosion and sedimentation rate estimation. Several high-tech instruments were utilized to determine radioisotopes activities as well as major and minor elements concentration, nutrient contents and physical properties of soil and sediment samples. In this section, experimental methods and relevant equipments are described. The appropriate experimental programmes were designed based on priority of analyses and desirable results.

Figure 3.9: Water quality survey at Bera Lake using Hydrolab DS5

3.3.1. Soil and Sediment Cores Preparation

Three hundred and fifty soil and sediment samples were prepared according to the standard instructions which published by IAEA (1983). Collected core samples were sealed and stored vertically to prevent mixing during transportation to the laboratory. Sample cores were preserved in a freezer at the temperature of 4 $^{\circ}$C before slicing. The main idea behind the core freezing was to minimize of compaction sediment column during slicing. The freeze sediment core samples were evacuated from core plastic tubes using an extruder. The extruder has a diameter lower than interior liner diameter of the core tube. The cores were sliced at 2±0.2-cm intervals using a plastic saw (Fig. 3.10). The sliced samples were dried at 60 $^{\circ}$C and ground for further analytical procedures. The dried samples were packed in special containers (Fig. 3.11) for three weeks before counting to allow the ^{226}Ra to secularly equilibrate with ^{222}Rn and its' shorter half-life daughters.

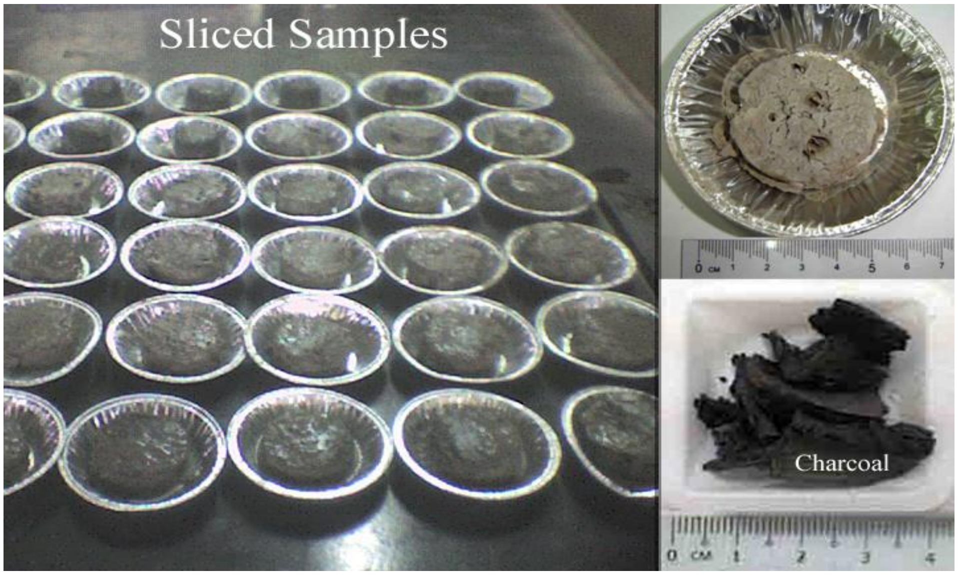

Figure 3.10: Sliced samples before and after drying and charcoal content

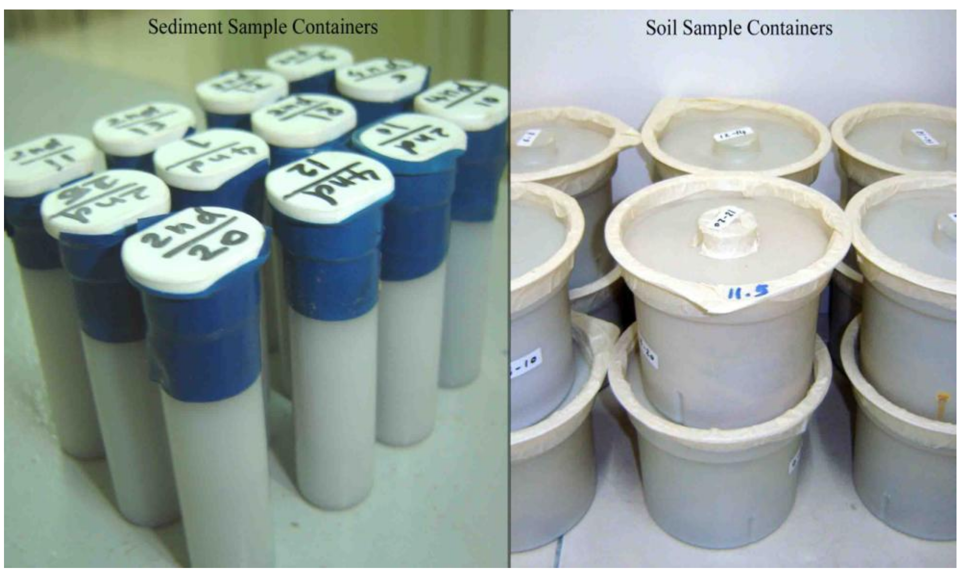

Figure 3.11: Packing of soil and sediment samples before radioisotope counting

In case of soil samples, the bulk and dry densities of the well preserved cylindrical core samples were determined after they had been dried at 80 to 105 $^{\circ}$C and weighed. The samples were then finely ground and packed in special containers for three weeks to allow secular equilibration of radioisotopes.

3.3.2. Radioisotopes Analysis

^{210}Pb and ^{137}Cs specific activities were measured using well calibrated gamma-spectrometry based on hyper pure germanium (HpGe) detectors at Nuclear Malaysia (Fig. 3.12) and Genie 2000 software Version 3.2. The gamma-spectrometer model GCW2523, (Canberra) detector at Nuclear Malaysia had a relative efficiency of 27% and FWHM of 2.04 keV for ^{60}Co gamma-energy line at 1332 keV. The gamma transmissions used for activity calculations was 46.5 keV with a branching ratio of 5.6084%. The gamma-spectrometer was calibrated using multinuclides standard (NIST) solutions in the same sample–detector geometry. The lower limit of detection, with 95% confidence, is 0.3 Bq for 24 hours measuring time. IAEA reference samples QAQC2 and QAQC6 were used for quality control of the gamma-spectrometer and its calibration.

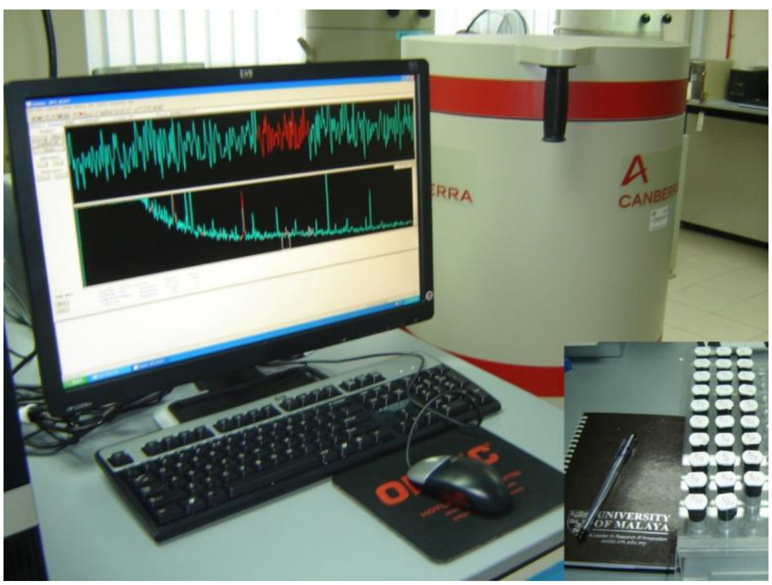

Figure 3.12: Gamma-spectrometer model GCW2523 used in this study

The defined energy spectrum in γ-spectrometric analyses include ^{7}Be, ^{54}Mn, ^{40}K, ^{57}Co, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{212}Pb, ^{210}Pb, ^{226}Ra, ^{226}Ra, and ^{228}Ra radioisotopes in which total activity of ^{210}Pb, supported ^{210}Pb, and ^{137}Cs were used in age calculation and determination of historical variation of sedimentation rate.

Disequilibrium between ^{210}Pb and its parent isotope (^{226}Ra) in the ^{238}U series arises through emission of the noble gaseous isotope ^{222}Rn (half-life ≈ 3.8 days). Escaped gas of ^{222}Rn to the atmosphere naturally decays to ^{218}Po, a metallic radionuclide which in a period of hours or days, precipitates to the earth with dust and rain. A number of daughters radioactive decays occur over a period of minutes and ^{210}Pb or unsupported ^{210}Pb (half-life=22.3yr) is produced. Supported ^{210}Pb in each sample was assumed to be in equilibrium with the *in situ* ^{226}Ra, and unsupported ^{210}Pb value was calculated by subtracting ^{226}Ra activity from total ^{210}Pb activity (Appleby, 2000).

3.3.3. Chemical and Pollution Analysis

According to Method 3052 (Kingston, 1998), weighed samples of 0.25 g were mixed with reagents, containing 9 ml of HNO_3^{1-}, 2 ml of HCl, and 3 ml of HF. Digestion procedures were continued using a Multiwave 3000 Oven (Fig. 3.13) with ramping and holding times of 5 and 10 minutes, respectively. Semi-digested samples were eventually fully digested by addition 18 ml of saturated boric acid solution (H_3BO_4) during complexation, followed by a holding time of 10 minutes in a Multiwave 3000 Oven. Digested samples were analyzed inductively coupled plasma mass spectrometry (ICP-MS) Model Agilent Technologies 7500 Series. Sediment data in this study are reported on a dry weight mg kg^{-1} basis.

3.3.3.1. Quality control

The analytical data quality was guaranteed through accomplishment of laboratory quality assurance and quality control methods, including the use of standard operating procedures, calibration with standards, analysis of reagent blanks, recovery of samples and analysis of replicates. All sediment analyses were performed by the quality-accredited laboratory of Geology, University of Malaya for the analyses of the sediment profiles, which were carried out at the Hydrogeo laboratory. Intra- and inter laboratory quality assurance and control (QA/QC) formed an integral part of the analysis schemes, e.g. by regular validation with reference sediment samples, the use of control charts and of replicates.

Freshwater lake sediment standard reference material (SRM No. 4354) was used for the quality control test and quantitative analysis. Six replicate samples, each with a mass of 0.25 g, were weighed, digested and analyzed by ICP-MS in a similar manner as the sediment samples. The blank and standard solutions were prepared for metallic elements in the order of 1, 2, 3, 10, 20, and 50 ppm. The percentage recoveries of the metallic elements in the samples ranged from 81.7% (Ca) to 110% (Mg). Results of the repeated and reference samples were found in an acceptable limit range (75-125%) for all analyzed metals and metalloids (Table 3.1).

Table 3.1: Quality control results of ICP-MS using SRMs (4354) freshwater lake sediment standard samples

Elements (mg/kg)	Al	Fe	Na	Mn	Mg	Ca	K	Pb	Cu	Zn	As	Ni	Cr
ICP Results	15495±552	23098±67	1906±264	449±13	1980±50	8664±352	1967±82	10±1	2312±40	94±9	139±8	8±2	20±1
SRMs	15000	26000	1800	430	1800	10600	2400	11	2400	88	150	9	22
Recovery %	103.3	88.8	105.9	104.4	110.0	81.7	82.0	90.9	96.3	106.8	92.7	87.0	90.9

Figure 3.13: Digestion using Perkin Elmer, Multiwave 3000 Oven

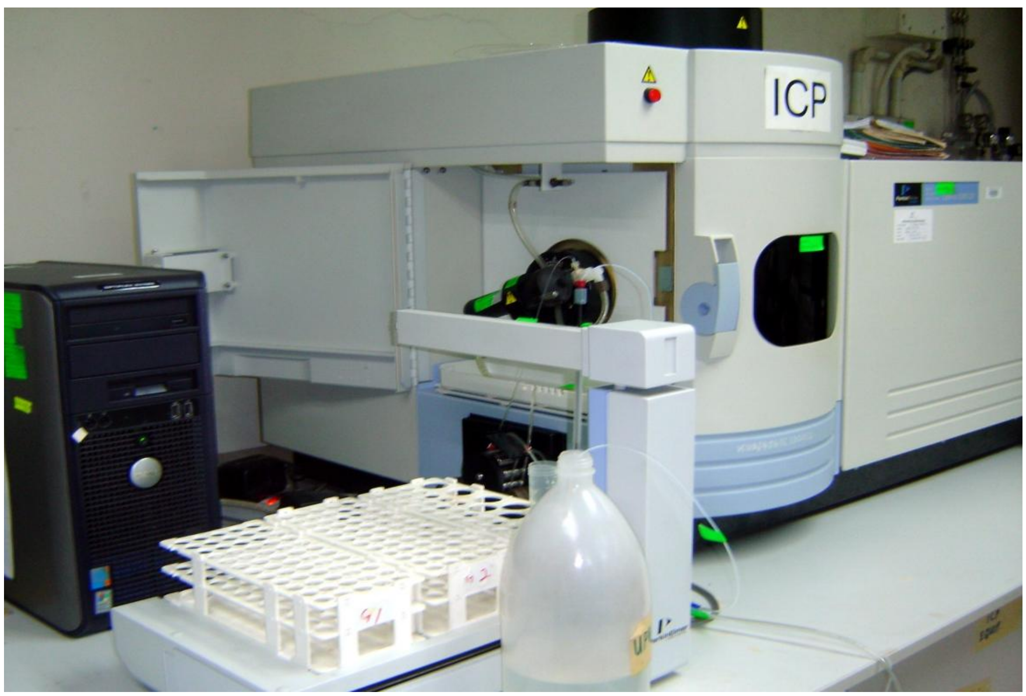

Figure 3.14: Inductively coupled plasma mass spectrometry (ICP-MS) Model Agilent Technologies 7500 Series

3.3.4. Nutrient Content Analysis

A total of 65 samples of Core 5 and Core 6 with a mass of 1-1.5 g were weighed and mixed with 1–2 ml of HCl 1 M to remove inorganic carbons, and were dried about 10 h at 100–105 °C to remove the HCl. Then, 0.5-2 mg samples were weighed and analyzed for Total Carbon (TC) and Total Nitrogen (TN) using PerkinElmer 2400 Series II CHNS/O Elemental Analyzer (Fig. 3.15).

Figure 3.15: PerkinElmer 2400 Series II CHNS/O Elemental Analyzer

This analytical method quantitatively determines the total amount of nitrogen and carbon in all forms in soil, botanical, and miscellaneous materials using a dynamic flash combustion system coupled with a GC separation system and TCD system. It based on the complete and instantaneous oxidation of the sample by "flash combustion" which converts all organic and inorganic substances into combustion gases (N_2, NOx, CO_2, and H_2O). The method has a detection limit of 0.01% for carbon and 0.04% for nitrogen and is generally reproducible within 5% (relative). TOC was measured by removal of carbonates from samples using HCl (1N) according to method presented by Schumacher (2002). An organic analytical standard (Acetanilide-C6H5NH) was used for quality control test and quantitative analysis. The quality control procedure was performed using Acetanilide standard sample as conditioner. Five blank-tin aluminum samples were tested. The calibration continued when positive results of C<50, H: 100~200, and N<16 were obtained. Then, three replicates Acetanilide samples, each with a mass of 0.5-2 mg, were weighed, and analyzed by Perkin Elmer 2400 Series II CHNS/O Elemental Analyzer. The calibration factors for carbon, hydrogen and nitrogen were respectively 71.09±0.3, 6.71±0.3, and 10.36±0.3 %, according to the instrumental instruction. The organic analytical standard (Acetanilide) was run for every four samples. CHN analysis was continued when the Acetanilide samples gained in the range of calibration factors.

3.3.5. Soil and Sediment Physical Properties Analysis

Grain size distribution, bulk density, moisture, soil, and porosity, soil and sediment classification are physical properties determined in this research. A total of 350 sediment samples were analyzed for mentioned physical properties, especially saturated and submerged densities. In addition, some 50 soil samples were analyzed for total and dry bulk densities. Grain size analysis was performed using ASTM 422 method in which the mechanical or sieve analysis was carried out to determine the distribution of the coarser, larger-sized particles, using the Master Seizer MALVERN was used to determine the distribution of the finer particles (Fig. 3.16). In addition, master seizer software was applied to draw grain size distribution diagram.

Figure 3.16: Mechanical shaker and Master Seizer model MALVERN

3.4. GIS Studies

Geographical Information System (GIS), known as advance tool in the geosciences to standardize multiple layers data, includes both human and physical, in the vector and raster formats, and provide spaces to import and geo- reference imagery such as satellite, aerial photographs, etc. (Dorall, 1997). GIS links geographical objects and locations to relational database which can organize and store practically unlimited number of objects and site characteristics in the form of numerical data, text, photograph, hyperlinks, sound and animation which are the standard technologies of multimedia information system these days. In addition, GIS meets the needs of modem management system, and offer to be the best management technique of analysis, visualization and of presentation, which no other management system can presently offer. Such a GIS literally provides a virtual environment for area management which is later validated by field visits (Dorall, 1997).

3.4.1. Map Development

ArcGIS Software Version 9.2 was utilized to develop a geo-referenced digital "GIS-ready" data set from previous paper-based maps, digital topographic maps, terrestrial and remotely sensed data, as well as surveyed and collected data in the real time. Horizontal positioning system was justified to national grid projected coordinate system, Kertau RSO Malaya Meter as well as to WGS, 1984. Previous GIS-ready data were digital topographic maps of L8028 Series (1:25,000 scales) and satellite image (Spot5, 2009) of spatial resolution 10 m which significantly have supported base maps developing. In addition, 200 aerial photos (flown in 1966 at an approximate scale of 1:25,000) of the BLC area were collected in order to prepare orthophoto or photo-mosaic. Several developed maps in this study were listed below and they will present in results sections.

3.4.1.1. Physiographic Maps

Contour lines of 20 meter interval derived from the digital topographic map of L8028 Series (1:25,000 scales) have been used to develop the basic physiographic maps. The DEM was created as basic map to develop elevation map. In addition, spot heights and stream network layers were overlaid on contour map in order to recognize and draw catchment boundary. Elevation map, stream pattern and sub-catchment map were developed after recognizing of catchment boundary.

3.4.1.2. Geology Maps

Geological map was prepared based on the national geological map scale of 1:250,000 published by Geological Survey of Malaysia (1972). Detailed and differentiated geological map of study area has not been studied. The boundary of each formation was checked by field observations and is in agreement with MacDonald's report (1970).

3.4.1.3. Land use Maps

FELDA districts maps were derived from the digital topographic maps of series L8028 (1:25,000 scale) which is described in the Appendix 1. A new land use map of the BLC area has been developed using GIS, a satellite image (Spot5, 2009) of spatial resolution 10 m and an on-screen digitizing method.

3.4.1.4. Bathymetric Map

One thousand and three hundreds of depth records were organized to export into spatial modeling and interpolation techniques (Ordinary Point Kriging) to develop bathymetric map. Initial bathymetric map was developed using Golden Software Surfer 7.0 and complementary mapping procedure was fulfilled by ArcGIS 9.2 software.

3.4.1.5. Water quality Maps

Nine hundreds records of water quality parameters at three different depths were categorized and exported into spatial modeling and interpolation techniques (Ordinary Point Kriging) to develop individual map of each parameter. Initial water quality maps were developed using Golden Software Surfer 7.0 and complementary mapping procedure was implemented by ArcGIS 9.2 software.

3.4.1.6. Sedimentation Map

Nine mean values of sedimentation rate from nine core samples were plotted and exported into spatial modeling and interpolation techniques (Ordinary point Kriging) to develop sedimentation map. Initial sedimentation map of Bera Lake was developed using Golden Software Surfer 7.0 and complementary mapping procedure was accomplished by ArcGIS 9.2 software.

3.4.1.7. Soil Map

For this purpose texture of thirty five soil samples were plotted at BLC area. In the first attempt, a spatial modeling and interpolation technique (Ordinary Point Kriging) was used for developing soil map. This method was reconsidered because of low sampling density and inter-fingering pattern of forest and reed swamps in study area. Significant relationship was found between the soil texture, land use and some sub-catchments. Similar soil texture classification in the adjacent land uses and sub-catchments resulted in a selective method in which similar soil texture districts were polygonized.

3.4.1.8. Soil Erosion Map

The soil redistribution mapping technique based on ^{137}Cs was introduced by Mabit (2007, 2008b) who utilized geostatistics coupled with a GIS to create a map of soil redistribution using spatial variability in ^{137}Cs activity. His method is applicable in a small catchment with similar land use and topographic conditions. Soil redistribution mapping in this study has been based on the land use and dates of tillage commencement as well as similarities in each sub-catchment. The FELDA land development schemes which have information on dates of tillage and elapsed time were the basic units for mapping. Soil erosion values obtained for cleared land with similar elapsed times were extended to other cleared lands within the same sub-catchment. Mean values of soil loss from undisturbed Malaysian rainforest were obtained from previous studies considering natural forest in the BLC. Furthermore, mean accretion rates for sink areas in BLC, were based on ten bulk core samples in the wetlands and open waters. The soil redistribution map of BLC is the first attempt in applying the ^{137}Cs technique in Malaysia and is appropriate to illustrate erosional and depositional trends in one of the largest catchments in Malaysia.

3.4.1.9. Nutrient content Map

There were constraints in terms of interpolation of nutrient contents of soil samples owing to low sampling density and inter-fingering pattern of forest and reed swamps in study area. There is a clear correlation between nutrient content and land use type but the results did not support polygonizing of similar nutrient content. Therefore, the nutrient content of soil samples were plotted on the land use map to show effects of land use changes on the nutrient concentration.

3.5. Modeling

3.5.1. Geo-chronological Models

There is a long history in application of radioisotopes techniques to date lake sediments of some 100 to 150 years old (IAEA, 1983). Goldberg (1963) and Krishnaswamy (1971) were leader to introduce this method. Dating of sediment profiles in lakes using ^{210}Pb is a more acceptable method when the accretion rate is relatively constant throughout the given time period. In such lakes, the concentration of ^{210}Pb exponentially decreases with depth at a rate that is inversely proportional to the sedimentation rate. This assumption has been commonly used in the Constant Initial Concentration (CIC) and the CF:CS which theoretically was explained by Robbins et al., (1978), Jeter (1999), Appleby (2001). Lakes that have experienced variations in sediment supply due to natural and anthropogenic impacts show a non-exponential reduction of ^{210}Pb concentration with depth. This assumption has been commonly used in the Constant Rate of Supply Model (CRS) (Appleby & Oldfield 1978; and Robbins et al., 1978). In addition, Pennington et al., (1973) and Appleby et al., (1991) have used ^{137}Cs and ^{241}Am as artificial radioisotopes derived from the atmospheric testing of nuclear bombs and from the 1986 Chernobyl reactor accident to validate ^{210}Pb resultant sediment ages. The basic models have been improved (Appleby & Oldfield 1983; Oldfield et al., 1984; Appleby 1998) in order to evaluate ^{210}Pb data and best interpretation of sediment chronology. The reviewed literatures also showed that IAEA is the first organization to introduce the use of radioisotopes in sediment studies (IAEA, 1983, 1995, and 1998).

3.5.1.1. The Constant Rate of Supply CRS Model

The CRS model assumes that the influx of excess ^{210}Pb supply to the sediment is constant with time at a particular location. The CRS dating model (1) is expressed as follows (Appleby and Oldfield, 1978b):

$$A_t = A_o e^{-\lambda t} \qquad (1)$$

where A_t is the cumulative $^{210}Pb_{ex}$ below the level representing time t, λ represents the ^{210}Pb decay constant of ^{210}Pb (0.03114 y^{-1}) and A_o is the total cumulative $^{210}Pb_{ex}$ inventory (Bq m^{-2}) at the point where the $^{210}Pb_{tot}$ activity reaches radioactive equilibrium with the supporting ^{226}Ra (2).

$$A_0 = \Sigma(\rho_i h_i A_i) \qquad (2)$$

where ρ_i =dry bulk density (kg m^{-3}) of the i_{th} depth interval, h_i =thickness of the i_{th} depth interval (m) and A_i =$^{210}Pb_{ex}$ (Bq kg^{-1}). Furthermore, ^{210}Pb flux (Bq m^{-2} y^{-1}) can be calculated with by the following equation (3):

$$^{210}Pb_{flux} = A_0 \times \lambda \qquad (3)$$

In addition, the age of the sediments (4) at any depth is given by:

$$t = \frac{1}{\lambda} In \frac{A_0}{A} \qquad (4)$$

Sedimentation rate (cm y^{-1}) is obtained by dividing mass flux (g cm^{-2} y^{-1}) on saturated bulk density (g cm^{-3}) (Table. 3.1). A mean sediment flux and sedimentation rate can be calculated by a slope regression model. When the In $^{210}Pb_{ex}$ is plotted against the, resulting profile will be linear, if reduction in $^{210}Pb_{ex}$ content decreasing exponential. The mean sedimentation rate (cm y^{-1}) for a given sediment column will be determined by dividing of constant decay on slope ($\frac{-\lambda}{slope}$) (Fig. 3.17). The resultant slope should be valid to calculate the mean sedimentation rate when a significant r value and $p<0.05$ establish.

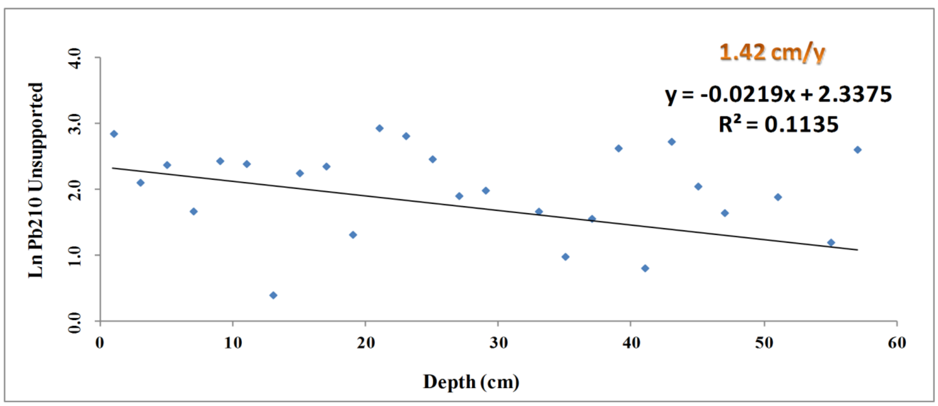

Figure 3.17: Mean sedimentation rate by plotting In ^{210}Pb against depth by CRS

The CIC model assumes the unsupported ^{210}Pb remains constant with time at a particular location and a constant sedimentation rate. As a result, the unsupported ^{210}Pb concentrations vary exponentially with depth. In most of recent sedimentary basins which has been affected extremely by anthropogenic changes and those are tectonically active, the assumption of the CIC model is extremely rare. However, in systems such as the remote lakes and the deep ocean where the system variations are minimized the CIC model may be applicable. The CIC dating model (5) is expressed as follows (Appleby and Oldfield, 1978b)

Table 3.2: CRS model running for calculation of sediment date, and flux

							Cum				Chronology		Estimated				Sedimentati
Dry Mass	Total Pb210		Ra226		Pb210 Conc		A		A		Age		Date	SAR		Density	Rate
g/cm^2	Bq/Kg	±	Bq/Kg	±	Bq/Kg	±	Bq/m^2	±	Bq/m^2	±	y	±		g/cm^2/y	±(%)	g/cm3	cm/y
0.00							0.00		1792.54	208	0.00	0					
0.32	61.1	8	41.2	6	19.96	10	64.69	33	1727.85	208	1.18	1	2008	0.27	51	0.21	1.28
0.63	51.0	7	34.5	6	16.41	9	119.72	43	1672.82	206	2.22	2	2007	0.32	56	0.18	1.75
0.93	94.5	10	34.1	6	60.45	11	234.40	56	1558.14	204	4.50	2	2004	0.08	22	0.19	0.43
1.18	65.0	8	32.2	6	32.78	10	353.36	62	1439.18	201	7.05	2	2002	0.14	32	0.08	1.73
1.44	65.0	8	32.2	6	32.78	10	437.02	67	1355.52	199	8.97	3	2000	0.13	33	0.07	1.88
1.69	65.0	8	32.2	6	32.78	10	520.69	72	1271.85	197	11.02	3	1998	0.12	33	0.09	1.30
2.09	45.3	7	34.7	6	10.68	9	606.62	80	1185.92	196	13.27	3	1996	0.35	84	0.12	2.96
2.48	45.3	7	34.7	6	10.68	9	648.85	88	1143.69	192	14.43	3	1995	0.33	84	0.25	1.35
2.83	65.6	8	49.3	7	16.29	11	696.05	96	1096.49	189	15.78	4	1993	0.21	66	0.36	0.59
3.20	61.3	8	37.2	6	24.06	10	771.09	103	1021.45	185	18.06	4	1991	0.13	44	0.37	0.36
3.60	38.0	6	35.4	6	2.59	9	824.19	108	968.35	181	19.78	4	1989	1.16	323	0.34	3.38
4.01	54.7	7	33.4	6	21.27	9	873.21	115	919.33	178	21.44	5	1988	0.13	46	0.34	0.40
4.41	69.2	8	47.8	7	21.36	11	957.73	123	834.82	174	24.54	5	1984	0.12	53	0.42	0.29
4.82	55.3	7	49.8	7	5.44	10	1012.99	130	779.55	168	26.74	5	1982	0.45	183	0.42	1.06
5.25	65.5	8	44.7	7	20.78	10	1069.52	138	723.02	163	29.16	6	1980	0.11	54	0.39	0.28
5.66	40.4	6	38.5	6	1.89	9	1115.07	142	677.47	156	31.25	6	1978	1.12	469	0.43	2.59
6.08	47.5	7	45.4	7	2.10	10	1123.59	148	668.96	152	31.65	6	1977	0.99	433	0.48	2.05
6.52	72.8	9	41.6	6	31.23	11	1197.29	156	595.25	147	35.40	7	1974	0.06	39	0.47	0.13
6.95	73.9	9	40.9	6	32.99	11	1334.95	163	457.59	138	43.85	9	1965	0.04	42	0.49	0.09
7.38	59.8	8	42.2	6	17.66	10	1441.80	168	350.74	130	52.39	11	1957	0.06	63	0.43	0.14
7.79	61.2	8	45.7	7	15.55	10	1510.47	174	282.07	123	59.38	13	1950	0.06	75	0.44	0.13
8.21	52.6	7	45.7	7	6.91	10	1558.08	179	234.46	115	65.32	15	1944	0.11	137	0.45	0.23
8.69	57.3	8	43.2	7	14.10	10	1607.99	185	184.55	107	73.01	18	1936	0.04	84	0.48	0.09
9.16	41.1	6	34.3	6	6.85	9	1657.07	189	135.47	96	82.94	22	1926	0.06	135	0.50	0.12
9.54	41.20	6	35.31	6	5.89	9	1681.76	192	110.79	87	89.40	25	1920	0.06	154	0.41	0.14
9.95	40.00	6	35.00	6	5.00	9	1703.96	196	88.58	80	96.58	29	1912	0.06	173	0.41	0.14
10.36	42.05	6	35.24	6	6.81	9	1728.12	199	64.43	72	106.80	36	1902	0.03	148	0.42	0.07
10.81	40.8	6	35.3	6	5.53	9	1756.03	203	36.51	62	125.04	55	1884	0.02	200	0.36	0.06
11.20	40.0	6	35.0	6	5.00	9	1776.40	206	16.14	48	151.26	96	1858	0.01	297	0.26	0.04
11.60	39.3	6	36.1	6	3.17	9	1792.54	208	0.00	34	#####	#####		0.00	#####	0.39	

3.5.1.2. The Constant Initial Concentration CIC Model

$$^{210}Pb_{ex(z)} = {}^{210}Pb_{ex(o)}e^{-\lambda 210 t} \qquad (5)$$

Where $^{210}Pb_{ex(z)}$ represents the unsupported (excess) activity of ^{210}Pb at the sediment-water interface. The radioactive decay constant λ_{210} for ^{210}Pb is $0.03114 y^{-1}$ and t is the deposition time (age, in year). The cumulative dry weight per unit area (g cm^{-2}), W, is related to the deposition time according to the expression t=W/f, where f is the sediment mass flux (g cm^{-2} y^{-1}). The least equation can be simplified and rewritten as follow (6)

$$In\ {}^{210}Pb_{ex\,(z)} - {}^{210}Pb_{ex\,(o)} = (\frac{-\lambda_{210}}{f})w \qquad (6)$$

A slope regression estimates a mean sediment flux in CIC model. When $In\ {}^{210}Pb_{ex\,(z)}$ is plotted against the cumulative dry weight per unit area, W, the resulting ^{210}Pb profile will be linear, with slope $\left(\frac{-\lambda_{210}}{f}\right)$. The sediment mass flux *f*, may then be determined from the mean slope of the profile, using the least-squares fit procedure (Fig. 3.18). The resultant slope should be valid to calculate the mean sedimentation rate when the significant is significant ($p<0.05$). However, results showed that in some cores, this model was reliable and represent similar results to other model although showed the weak correlation values.

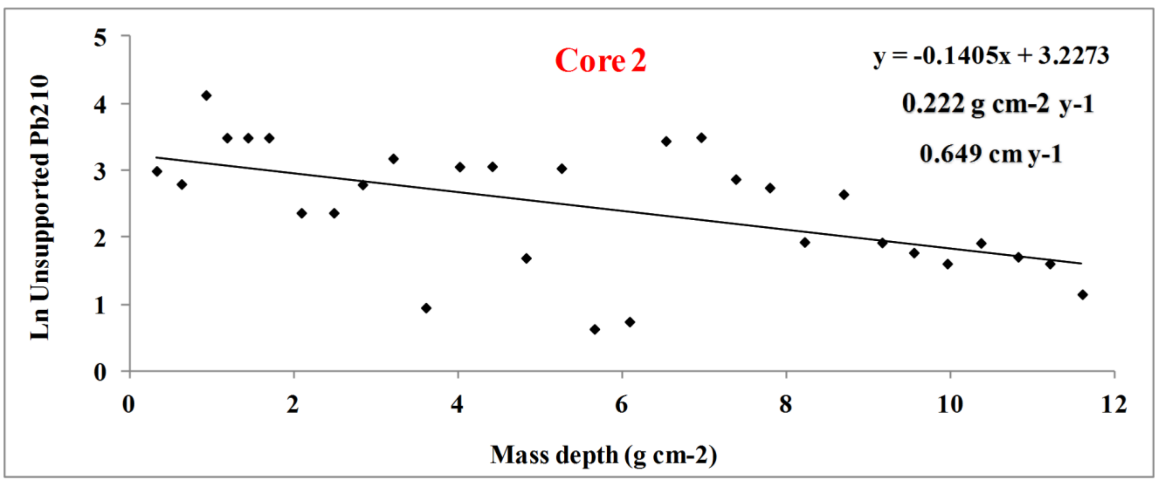

Figure 3.18: Mean sedimentation rate by plotting $In\ {}^{210}$Pb against mass depth by CIC

3.5.1.3. The Limitation of Models

In the real world, cores often show a non perfect trend and exhibit deviations from the ideal data set:

1) The data may reveal a vertical ^{210}Pb activity profile in the core surface. This can happen due to mechanical mixing of the surface sediments contributed by benthic organisms or by hydrodynamic activity of the overlying water.
2) The ^{210}Pb activity shows a peak slightly below the sediment surface. This is commonly seen and may be caused by steep redox gradients across the uppermost few centimeters of sediment.
3) The deepest sections analyzed may still appear to be above background levels of ^{210}Pb, as evidenced by a non vertical profile in the deepest part of the core.
4) Necessity to an independent time marker

In the case of (1) and/or (2), the data may still form a straight line on a log [excess ^{210}Pb activity] vs. cumulative dry sediment plot if the upper part of the core data is disregarded. This will allow the determination of accumulation rate for the mid portion of the core. If one assumes that the accumulation rate has remained constant in the upper, more recent sediments, then the age of the sediments can be calculated for any depth in the core.

In case (3), where the deepest core sections appear to be above background level, the excess ^{210}Pb activity cannot be calculated because there is no estimate of the background level of ^{210}Pb. It is necessary to make an assumption that the background level is less than the lowest activity measured in the core but greater than zero.

Independent tracer provides an unambiguous time stratigraphic horizon (Pennington, 1973; Robbins et al., 1978; Smith, 2001). Independent time marker in case (4) recommended the statement firmly. The well known independent time index is fallout ^{137}Cs which has been introduced firstly by Pennington (1973) as a verification time tool.

^{210}Pb considered is verified by subsurface ^{137}Cs peaks in sediments located at depths where ^{210}Pb dates agree with the date fallout maximum, 1963-1964. Furthermore, non radiological markers and depositional history, such as varves, known contaminant inputs, or known natural episodic events, and certain anthropogenic activities are used commonly as time signals. In this study the accuracy of ^{210}Pb dates was validated by referencing to well-known ^{137}Cs horizons. The validation is proven by its first appearance in sediment columns (1952-1954), the maximum atmospheric fallout from testing of atomic bombs (1963-1964) and the Chernobyl reactor accident (1986), charcoal horizons, and special influx of heavy metals, nutrients and exchangeable cations.

3.5.2. Soil Redistribution Models

In qualitative approaches to estimate soil redistribution in any area, the ^{137}Cs inventory at individual sampling points needs to be compared with a reference inventory from a site representing the local fallout input and where there is neither erosion nor deposition. A measured inventory value for an individual sampling point that is less than the reference value is thus indicative of erosion, whereas an inventory value greater than the reference value pointed out deposition. Poreba (2006) has noted that different empirical and theoretical models have been developed to convert ^{137}Cs measurements to quantitative estimate of erosion and deposition rates (Rogowski and Tamura, 1970; Walling and Quine, 1990; Walling and He, 1999). A PC-compatible software package has been introduced by Walling and He (1999), contains an advanced model that can be used for both cultivated and uncultivated areas as well as contribution of fallout ^{210}Pb and ^{7}Be radionuclides. The Proportional Model, Mass Balance I, II, and III, Profile Distribution

Model and Diffusion and Migration Model were developed for cultivated and uncultivated land in different situations (Walling & He, 1999). Application of each model requires establishment of several parameters and the recognition that the individual model, is different in terms of its underlying assumptions, process description and representation of temporal variation (Walling, 1999) (Table 3.2).

Application of the models to the study area revealed problems in estimating erosion rate on deforested land, as the FELDA districts had been first cleared of natural forest and exposed before being planted with, and covered by, oil palms or rubber trees. The mass balance models could be not used under these conditions as the models assume that the soil is cultivated every year or most years, and the soil is well-mixed with ^{137}Cs uniformly distributed within the plough layer.

Table 3.2: List of parameter requirements for individual models

Model	**Parameters required**
Proportional model and Simplified mass balance model	Tillage depth, bulk density, year of tillage commencement
Mass balance model	Tillage depth, year of tillage commencement, proportional factor, relaxation depth, annual fallout flux*
Mass balance model with tillage	Tillage depth, tillage constant, proportional factor, relaxation depth, slope length and slope gradient for each section of the transect, annual fallout flux*
Diffusion and migration model	Diffusion coefficient, relaxation depth, migration coefficient, annual fallout flux*
Profile shape model	Profile shape factor

* Only required for ^{137}Cs models

Although the proportional model, which has been used by some researchers to estimate erosion rates on cultivated land, has been shown to be inappropriate for normal cultivated soils, it can in fact be also suitable for soils that were cultivated initially and then remain uncultivated (Walling, 1999). For this model the amount of soil loss is calculated from the ratio of the ^{137}Cs measured at a sampling point to the local reference inventory; the proportion of the original ^{137}Cs (represented by the reference inventory) thus indicating what has been lost. It is also necessary to assume that little or no erosion occurred under the original forest cover. This is a reasonable assumption for the BLC area which was covered by dense rainforest prior to deforestation and development. In addition, it can be assumed that activities associated with the forest clearance are responsible for the mixing and existence of ^{137}Cs into the plough layer or tillage depth. The equation for this model can be written as follows (Walling & Quine, 1990):

$$Y = 10 \frac{BdX}{100TP} \qquad (1)$$

where:

Y = Mean annual soil loss (t ha^{-1} yr^{-1});

d = Depth of the plough or cultivation layer (m);

B = Bulk density of soil (kg m^{-3});

T = Time elapsed since the initiation of ^{137}Cs accumulation or commencement of cultivation, whichever is later (yr);

X = Percentage reduction in total ^{137}Cs inventory defined as $(A_{ref} - A)/(A_{ref} \times 100)$

A_{ref} = Local ^{137}Cs reference inventory (Bq m^{-2});

A = Measured total ^{137}Cs inventory at the sampling point (Bq m^{-2});

P = Particle size correction factor for erosion.

According to Turner, (2003) the mean tillage depth for cultivated oil palm/rubber farms has been 0.3 m. The default value for the particle size correction factor for erosion of P=1 in the PC-compatible models (Walling, 1999) was used in the running of proportional model. Details of the other conversion model with their advantages and limitations are available in Walling (1999).

3.5.3. Ecological Risk Assessment Models

The wide range of sediment quality indices have been used for the assessment of sediment quality and ecological risk in Bera Lake, C_f, C_d, E_r, and *RI* (Hakanson 1980), and EF (GIPME, 1999). According to Hakanson's work, a sedimentological risk index for toxic substances in aquatic systems needs four factors, 1) heavy metal concentration, 2) C_f and C_d, 3) Toxic factor, and 4) Sensitivity or response of environment.

$$C_d = \sum_{i=1}^{7} C_f^7 = \sum_{i=1}^{7} \frac{C_{0-1}^i}{C_n^i} \qquad (1)$$

where C_f and C_d are the contamination factor and degree of contamination, respectively. Seven heavy metals were essentially analyzed for this purpose i.e. As, Zn, Pb, Ni, Cd, Cr, Cu. Further, C_{0-1}^i and C_n^i are the heavy metal concentration in the superficial sediment (0-1cm) and natural or pre-industrial reference concentration level, respectively. There are four categories for contamination factor, i.e., 1) low contamination for which $C_f<1$, 2) moderate contamination for which $1\leq C_f\leq 3$, 3) considerable contamination for which $3\leq C_f\leq 6$, and 4) very high contamination for which $C_f\geq 6$. The categories defined by Hakanson (1980) for contamination degree are 1) low contamination for which $C_d<8$, 2) moderate contamination for which $8\leq C_d\leq 16$, 3) considerable contamination for which $16\leq C_d\leq 32$, and 4) very high contamination for which $C_d\geq 32$.

$$RI = \sum_{i=1}^{7} E_r^i = \sum_{i=1}^{7} T_r^i \times C_f^i \qquad (2)$$

where the requested potential ecological risk is RI for lake, and E_r^i is potential ecological risk factor for each individual heavy metal. In addition, T_r^i is the toxic response factor for the given heavy metals. Hakanson (1980) presented T_r^i values for seven heavy metals, i.e., Cr=2; Zn=1; Cu=Ni=Pb=5; As=10; and Cd=30. Further, Hakanson (1980) provided categories for indices and grades of potential ecological risk of heavy metal pollution, i.e., (1) low risk for which $E_r^i < 40$, (2) moderate risk for which $40 \le E_r^i \le 80$, (3) considerable risk for which $80 \le E_r^i \le 160$, (4) great risk for which $160 \le E_r^i \le 320$, and (5) very great risk for which $E_r^i \ge 320$. Furthermore, categories for potential ecological risk index were defined as (1) low risk for which $RI<150$, (2) moderate risk for which $150 \le RI \le 300$, (3) considerable risk for which $300 \le RI \le 600$, and (4) very high risk for which $RI \ge 600$.

The EF is another sediment quality index which has been widely used in this research. This index was introduced initially by Loring (1995) and has been further developed by Sutherland (2000) for the evaluation of anthropogenic effects. The EF can be used to differentiate between the metals that are present due to anthropogenic effects and the metals from natural sources so that the extent of anthropogenic influence can be estimated.

$$EF = \frac{(M/N)O_{bs}}{(M/N)N_{at}} \tag{3}$$

where EF is the metal EF for the sediment $(M/N)O_{bs}$ is the metal: normalizer ratio observed for the sediment; and $(M/N)N_{at}$ is the natural metal: normalizer ratio. Elemental concentrations, including metal concentrations, can be compared with reported natural occurrences of the metals in the sediment and/or in crustal rocks by normalizing against geochemical markers (e.g., Al and Li) of the predominant natural mineralogical phase (GIPME, 1999). Five contamination categories were identified by Sutherland (2000) on the basis of the EF, i.e., (1) deficiency to minimal enrichment for which $EF<2$; (2) moderate enrichment for which $2<EF<5$; (3) significant enrichment for which $5<EF<20$; (4) very high enrichment for which $20<EF<40$; and (5) extremely high enrichment for which $EF>40$. The normalaizer Al was used for calculating of EF of major and minor elements at Bera Lake sediment column.

Index of Geoaccumulation (Igeo) introduced by Muller (1979) for finding out metals contamination in sediment, by comparing gained concentration of heavy metals with background levels of each individual metals (Equation, 4).

$$I_{geo} = Log_2[C_n / 1.5 * B_n] \tag{4}$$

Where C_n is given metal levels and B_n is the background value of the given element in the study area and 1.5 is the background matrix correction factor owing to lithogenic effects. Index of Geoaccumulation classified by Muller (1979) as 1) zero value unpolluted for which $I_{geo}=0$, 2) unpolluted to moderately polluted for which $0<I_{geo}<1$, 3) moderate polluted for which $1<I_{geo}<2$, 4) moderate to strongly polluted for which $2<I_{geo}<3$, 5) strongly polluted for which $3<I_{geo}<4$, 6) strong to very strongly polluted for which $4<I_{geo}<5$ and 7) very strongly polluted for which $I_{geo}>5$.

3.5.4. Comparison of Heavy Metal Concentration with Standard Levels

The most common method to reveal adverse effects of heavy metals in sediments for aquatic life and human health is to compare their concentrations with the sediment quality guidelines which have been developed by the various environmental protection agencies. In this research, ISQG, PEL (CCME, 1995), CBSQG (CBQG, 2003), LEL, and SEL (Persaud, 1993) sediment quality guidelines were used to compare the heavy metal concentrations observed in the sediment cores (Table. 3.4).

Table 3.4 Sediment quality indices which were applied in this study (mg kg^{-1})

Sediment Quality Indices	V	As	Cr	Zn	Cu	Ni	Pb	Mn	Cd	Fe
LEL	–	**6**	**26**	**120**	**16**	**16**	**31**	**460**	**0.6**	**17,000**
ISQG	–	**5.9**	**37.3**	**123**	**35.7**	–	**35**	–	**0.6**	–
CBSQG	–	**9.8**	**43**	**120**	**32**	**23**	**36**	**460**	**0.99**	**20000**
PEL	**150**	**17**	**90**	**315**	**197**	–	**93.1**	–	**3.5**	–
SEL	–	**33**	**110**	**270**	**110**	**50**	**110**	**1100**	**9**	**25,000**

The lowest effect level (LEL) is a measure of contamination that has no effect on the majority of the sediment-dwelling organisms indicating that the sediments are clean to marginally polluted. Contamination in sediments that exceeds the lowest effect level may require management plans.

The severe effect level (SEL) indicates a heavily polluted condition that is likely to affect the health of sediment-dwelling organisms. Heavy metal concentrations that exceed the SEL require further toxicity analysis (Persaud, 1993).

The PEL represents the lowest limit of the range of chemical concentrations that are usually or always associated with adverse biological effects. The ISQG and the PEL are used to define three ranges of chemical concentrations for a particular chemical, i.e., those that are rarely (<ISQG), occasionally (between the ISQG and the PEL), and frequently (>PEL) associated with adverse biological effects (CCME, 1995).

The CBSQGs, as developed, only involve effects to benthic macro-invertebrate species. Several databases created by toxicological research projects have established the cause and effect correlations of sediment contaminants to benthic organisms and benthic community assessment endpoints (CBSQG, 2003). The guidelines do not consider the potential for bioaccumulation in aquatic organisms, subsequent food chain transfers, or effects on humans or wildlife that consume the upper food chain organisms.

3.5.5. Grain Size and Statistics Programme

Grain size distribution diagrams and calculation of statistical parameters were achieved by GRADISTAT, Version 6.0 (Blott & Kennet, 2001). The program is best suited to analyze data obtained from sieve or laser granulometer analysis. For this purpose, the mass or percentage of sediment retained on sieves spaced at intervals, or the percentage of sediment detected in each bin of a Laser Granulometer was transferred to GRADISTAT. The following sample statistics are then calculated using the Method of Moments: mean, mode(s), sorting (standard deviation), skewness, kurtosis, D_{10}, D_{50}, D_{90}, D_{90}/D_{10}, D_{90}-D_{10}, D_{75}/D_{25} and D_{75}-D_{25}. Grain size parameters were calculated arithmetically and geometrically (in microns) and logarithmically (using the phi scale) (Krumbein & Pettijohn, 1983). Linear interpolation was also used to calculate statistical parameters by the graphical method (Folk and Ward, 1957) and derive physical descriptions (such as “very coarse sand” and “moderately sorted”). The program also provides a physical description of the textural group which the sample belongs to and the sediment name (such as “fine gravelly coarse sand”) after Folk (1954). Table that gives the percentage of grains falling into each size fraction, modified from Udden, (1914) and Wentworth (1922) is also included. In terms of graphical output, the program provides graphs of the grain size distribution and cumulative distribution of the data in both metric and phi units, and displayed the sample grain size on triangular diagrams.