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ESTIMATION OF SEDIMENT RATES AND PATTERN IN SAGAR LAKE USING RADIOMETRIC DATING TECHNIQUES

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PREFACE

Lakes play an important role in shaping the hydrological, ecological and environmental balance of the region by developing flora, fauna and habitation of aquatic biota. The major problems being noticed from the lake are deterioration in water quality and increasing sedimentation rate. Sedimentation in the lake reduces storage capacity, light penetration and encourage biotic growth and affects the functioning of lake ecosystem.

The Sagar lake is situated in the middle of the Sagar district of Madhya Pradesh. The district is named after this water body indicating the historical significance of the lake. This water body was the source of perennial water supply to the town nearly half a century since 1912.

Sagar lake receives sediment through the Kanera canal. Deforestation, construction activities in the lake catchment and inflow from agricultural lands have accelerated the sedimentation rate in the lake. Local authorities are worried that the Sagar lake is being filled up by sediment at a faster rate and lake volume is reducing fastly.

Keeping in view the above concern, Regional Coordination Committee of the Ganga Plains South Regional Centre has recommended to carry out the sedimentation study of Sagar lake. For the first time, sedimentation rate and its pattern in the lake has been investigated using ^{137}Cs and ^{210}Pb dating techniques. Life of lake based on Post-1964 average sedimentation rate has been predicted. This study will be helpful in preparing the strategies for environmental management of the lake.

This report is prepared by Dr. Surjeet Singh Sc. 'C', Sh. L.N. Thakural, 'SRA' Ganga Plains South Regional Centre, Sagar and Dr. Bhishm Kumar Sc. 'F' of NIH HQs Roorkee, Dr. Rm. P. Nachiappan, Sc. 'B' helped in the measurement of ^{137}Cs and ^{210}Pb activity at the Nuclear Hydrology Laboratory at NIH, Roorkee including computation of the dating results.

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ABSTRACT

Sagar lake is situated in the middle of the Sagar city at an elevation of 517 meters above mean sea level in the Vindhyan terrain of Bundelkhand region. Lake surface area is 145 ha at full tank level. The maximum depth is 5.3 meter. The maximum length and width of the lake are 1247 metres and 1207 metres, respectively. The lake mean depth is 2.69 metres. Volume of the lake is 389 ha-m. Catchment area of the lake is 1817 ha.

Sedimentation rate and pattern in lake have been carried out using ^{137}Cs and ^{210}Pb radiometric dating techniques. Sedimentation rate in the lake varies between 0.14 to 1.68 cm/y depending upon the location in the lake. The mean sedimentation rate is 0.956 cm/y. In the present study, lake has been subdivided into eight zones on the basis of sedimentation rate and under water topography and the lake life has been estimated. The estimated life based on Post-1964 average sedimentation rate of the lake is around 467 years.

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1.0 INTRODUCTION

Sediment is carried into the lake by streams, rivers as well as overland flow entering into the lake. Delivery of sediment depends upon slope, vegetation cover and geology of the lake catchment. Human activities such as deforestation, agricultural activities and disposal of domestic waste have accelerated sedimentation rate in lakes. Sediment entered into the lake deposits slowly on the lake floor as natural processes of sedimentation. Sedimentation in the lake reduces storage capacity, light penetration and encourage biotic growth and affects the functioning of lake ecosystem (Bhargava and Mariam, 1991). Sediment from agricultural lands and hilly terrain are major source of pollutants in rivers, lakes and reservoirs. Sedimentation in lakes and reservoirs record the effects of climatological or man-made changes in and around the catchment of the lakes. Sly (1978) outlines several factors influencing the sedimentation processes in lakes. Generally, land-derived sediments carried into lakes by streams or other agencies settle on lake floor. Therefore, they act as perfect settling basins. Delta growth in lakes is particularly strong because of absence of very appreciable tides and the usual lack (except in some very large lakes) of very powerful wave and undertow action.

Fastly deteriorating conditions of the lake has posed a serious threat to the existence of lake. In recent years, developmental activities in the lake catchment has accelerated the sedimentation rate. In this connection, sedimentation rate study has been carried out for the Sagar lake situated in the Sagar district.

Sagar lake is a prominent lake located in the middle of Sagar city. The lake is divided into two parts, the main lake and small lake. The Sagar lake was the source of perennial water supply to the town nearly half a century since 1912. Presently the water is being supplied to the Sagar town from Rajghat dam (minor project) nearly 12 km away from the city. It is also famous for its historical importance. A large number of construction activities has also taken place in the lake catchment. It has been felt that the Sagar lake is shrinking fastly due to higher rate of sedimentation. For proper management of the lake water body it is essential to study the sedimentation rate and pattern in the lake. In the present study, sedimentation rate of Sagar lake has been estimated using ^{137}Cs and ^{210}Pb dating techniques and life of the lake has also been determined.

2.0 STUDYAREA

Sagar lake is situated in the middle of Sagar city. Sagar city falls a few kilometers to the North of Tropic of Cancer at an altitude of 517 m above mean sea level in the Bundelkhand region and at the latitude of 23 50' N and longitude of 78 45' E and it can be seen on toposheets No. 55I/13 and 55I/9. There are a number of small inflowing channels into the lake carrying city waste water. The lake receives fresh water from the precipitation over the lake basin area, which flows into the lake through overland flow. During the rainy season, when water level rises in the lake, overflow from the lake takes place through Mogha weir only. Lake water level varies between 525.00 to 526.75 m above mean sea level in a year, it reaches maximum in July/August and minimum in May/June.

Climatically, the area falls under semi-arid to sub-tropical region. Monsoon rains are received from June to September and the winter rains during December to February. The average annual rainfall is nearly 110 cm. Air temperature varies between 5 C (minimum) in winter to 43 C (maximum) during peak summer.

2.1 Geology of the Area

The geological formation of the lake bed mainly comprises of quartzite sandstone of Vindhyan age and the Deccan traps. The Deccan traps are basaltic in nature having vertical, polygonal and columnar joints. The Vindhyan quartzite sandstone is hard and compact with nearly vertical joints. The bedding planes are thickly bedded and horizontal having low porosity. These joints behave like channels for water infiltration. The ground water recharge is very poor, i.e., only 10 to 15 % of the total rainfall is percolated to the ground water (Krishnan, 1967).

The soils of this area are of two types - the red or reddish brown lateritic soil on hill tops and the black soil at the foothills. The vegetation of Sagar district can be included under Northern tropical dry deciduous forest (Krishnan, 1967).

2.2 Morphometric Characteristics

The lake under investigation has periphery of 5230 m with maximum length 1247 m, width 1207 m. Mean depth of the lake is 2.69 m with maximum depth of 5.3 m at full tank level. The lake is divided into two parts, the main lake with water spread area of 107.7 ha at full-tank level and the small lake with water spread area of 37.03 ha. The volume of the lake is 389 ha-m at full-tank level. The catchment area of the lake is 1817 ha, out of which the total water spread area is 145 ha at full-tank level. The landuse pattern of the basin is 40.9 % barren land, 20.9 % agriculture, 18.7 % settlement, 11.5 % open forest and 8.1 % water body. The index map and geomorphological map of the Sagar lake catchment are shown in Fig. 1 and 2.

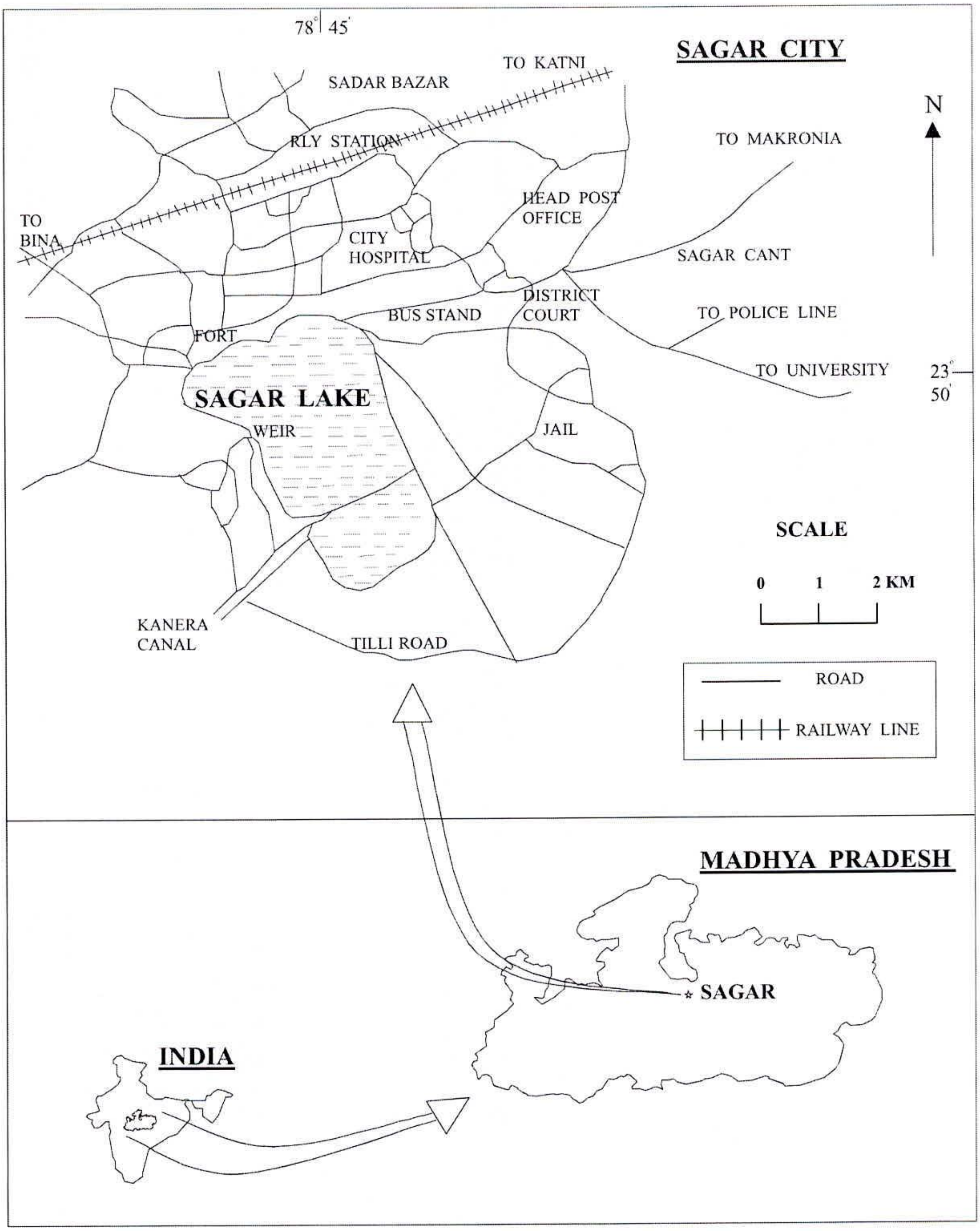
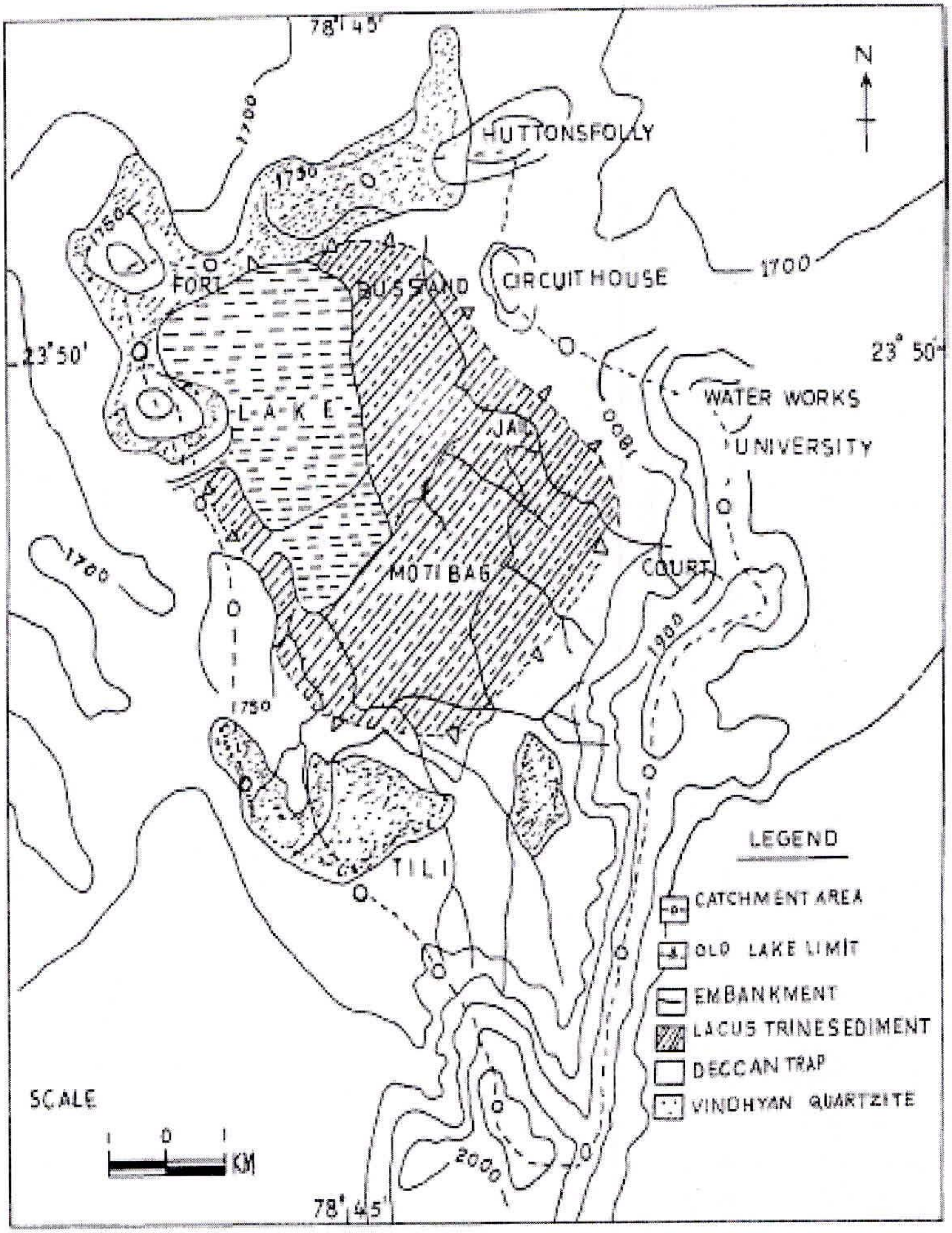


Fig. 1: Index map of Sagar lake



(SOURCE AGARWAL, 1991)

Fig. 2: Geomorphology of Sagar lake

2.3 Origin of the Lake

The lake under investigation is two hundred years old. Historical records assign an artificial origin whereas geological evidences are in favour of natural origin of this lake (Mishra, S.K., 1969). Geological evidences also say that originally the lake had an area of 580 ha as against the present 145 ha (Yatheesh, 1990). The maximum depth was about 60 feet as against the present depth of about 16 feet. The lake is having a drainage pattern, i.e., north-west ward, in concordant with that of the district (Krishnan, 1967).

3.0 BRIEF SUMMARY OF PREVIOUS WORK

Prof. W.D. West (1964) (vide Krishnan, 1967) suggests different theories of existence of the Sagar lake. Historical records assign an artificial origin whereas geological evidences are in favour of natural origin of the lake. The Water Resources Department, Sagar, M.P. has estimated the annual rate of silt deposition as 0.062 ha-m per sq.mile of catchment area. Recently in a project , Forest Department, Sagar, M.P. has estimated the total annual quantity of silt deposition to be 0.45 ha-m in which 55 % is contributed from the built-up free catchment area of 4.08 sq.mile and rest is contributed from the catchment area of 3.22 sq.mile through the feeder Kanera canal. In another project by PHED, Sagar, M.P. (1997) it is said that the silt deposition in the whole area of small lake is at the rate of 3.25 cm per year and with the present rate of siltation, the small lake will be filled up in the next thirty to forty years.

Most of the scientific studies carried out on the Sagar lake have concentrated on the physico-chemical properties of the lake water and the possible inter-relationship and interactions between their properties and biological factors like plankton, macrophytes, macrofuna, etc. The first study of this kind on the micro-biological aspects was published in the year 1975 (Adoni, 1975). Thereafter a number of studies on the lake water were published in the year 1980 (Awatramani, 1980), 1986 (Yadav, 1986) and 1990 (Yatheesh, 1990). Among these studies, most of them are Ph.D. thesis available in the university library and some are state govt. publications.

Among the studies on the Sagar lake, diurnal variations have been studied by Saxena and Adoni (1973), Thakur and Bais (1986) and Joshi (1987). Studies related to Macrophytes have been done by Singhal (1980) and Yadav (1986) and Yatheesh (1990) has studied the trophic status with special reference to macrobenthic-invertebrates. Awatramani (1980) and Ghosh (1986) have done limnological studies of some aquatic ecosystems of Sagar lake. Some ecological studies on and surrounding the lake have been done by Saran (1980), Babu and Tamrakar (1987) and Gupta (1987). Thakur and Bais (1986 & 1987) have conducted chemical analysis of lake water. Agarwal and Bais (1991) has done the hydrobiological study on the lake. The studies done on the Sagar lake have focused on biological, chemical and ecological aspects. The general observations of these studies show a high trophic status and a high organic pollution level in the Sagar lake. Recently one status report has been prepared by Sinha and Thakural (1998). In this report, efforts are made to compile all possible published work on the Sagar lake. This includes brief description of the histrological and the geographical background of the lake, details of water quality analysis carried out in various years, present status of the lake and various schemes proposed and implemented for the improvement of pathetic condition of the lake. The hydrological study on the water balance of Sagar lake has been done by Singh and Thakural (2000).

Various workers have made attempt to understand the ecological aspects of Sagar lake but no attention has been paid to the study of sedimentation in Sagar lake. Sedimentation study of various lakes such as Nainital, Bhimtal, Naukchiyatal and Sattal has been studied by conventional and Radiometric dating techniques. Das et al. (1994) have determined the sedimentation rate of Kumaun lakes using ^{210}Pb and ^{226}Ra dating techniques. Kusumgar et al., (1989) have studied radiocarbon chronology and magnetic susceptibility variations in the Kumaun lakes. Bhishm Kumar et. al. (1999) have determined estimated life of lake Nainital as 2480   310 years using ^{210}Pb sedimentation rate and 2160   80 years using ^{137}Cs sedimentation rate. Various workers (Hukku et al., 1968; Sharma, 1981; Rawat, 1987) have studied the sedimentation rate using sounding data of lake Nainital and predicted life of Nainital lake which vary from 82 to 380 years.

4.0 METHODS OF DETERMINATION OF SEDIMENTATION RATE IN LAKES

There are various techniques for the determination of the sedimentation rate of lake/reservoirs. Various methods to determine the sedimentation rate in lakes are discussed in brief. The ^{137}Cs and ^{210}Pb dating techniques have been described in detail, which are used in the present study.

4.1 Range Line Method

The range-line method is widely used for medium to large lakes and reservoirs requiring an underwater survey utilising hydrographic surveying methods. In range line method, a number of cross sections, called ranges, of the lakes are surveyed and then it is periodically repeated at the same cross sections. Specific details concerning the method can be found in many references (Vanoni,1977; Guy, 1978; and Eakin,1939). Basically, the deposition of sediment during a period is estimated by measuring the depth of bottom surface (water column) at different locations which can be compared to a previously constructed map to determine differences in the volume of sediment deposited.

4.2 Contour Method

The contour method uses essentially topographic mapping procedures (Wolf, 1974). To apply this method, it is important to have a good contour map of the lake when it is dry (Pemberton and Blanton, 1980).

The procedure for either method involves the determination of bed elevation at many known locations in the lake/reservoir. These measurements are always made by measuring the water depth beneath a boat and the exact location of the boat on the lake's surface. Water depth at any point can be measured by using a sounding weight, a pole or sonic sounding equipment etc.

The other basic measurement required for a lake/reservoir survey is the location of the boat at the time the depth is measured. Many manual techniques have been used to determine the boat position. The simplest which is useful on small lakes is to use a tag line. For larger lakes the boat has often been located by triangulation methods using transits on shore. Global Positioning System (GPS) may also be used for positioning the lake. Once the data, consisting of water depths and locations, have been obtained they can be used to compute storage capacity, sediment deposition rates or area capacity tables.

4.3 Sediment Balance Method

Sediment is carried into a lake by streams and rivers as well as by overland flow entering a lake. Sediment entering a lake may consist of a wide range of sizes, from gravel or boulders to silt and clay particles.

The surest way of obtaining an accurate determination of the amount of sediment being carried to a lake by streams is to measure the flow rate and sediment concentration of the inflowing waters just upstream of the lake. Ordinarily, records of sediment discharge (fine, coarse, suspended, or bedload) are determined on the basis of sample information obtained at non-uniform intervals of time. The information from the sediment samples can be used to estimate the total sediment discharge by developing a relation between the sediment discharge and water discharge, called a sediment transport curve. The sediment outflow from the lake, if any, is computed in the discharges from the lake. The difference of input and output sediment divided by lake area gives the sediment deposition rate.

4.4 Remote Sensing Techniques

Low level remote sensing has several main applications in the assessment of lake/ reservoir sedimentation. Contour maps prepared from aerial photographs can be used to determine sediment volumes provided the water level can be lowered greatly. Aerial photography can be used to trace turbidity plumes which may help in defining the distribution of sedimentation. Digital image processing of high resolution satellite data can also be used for lake sedimentation studies. The information of suspended sediments obtained at different times using this technique can be utilised to predict the deposition or settling rate of sediments in the lake.

A comparatively new technique which being developed by the U.S. National Ocean Survey is to use laser hydrography (Enabnit et.al., 1979). The airborne laser hydrographic technique uses an aircraft mounted, pulsed laser system to collect a swath of discrete soundings along each flight line. It measures water depth exactly like a sonar using light instead of sound.

4.5 Radiometric Dating Techniques

Several environmental isotopes including ^{210}Pb, $^{137}C_s$ and ^{14}C find applications in the estimation of sedimentation rate in lakes. However, ^{14}C is more useful for paleo-hydrological studies (Kusumgar et al., 1992). Artificial radio-isotopes used for sediment accumulation studies include ^{239}Pu, ^{240}Pu and ^{241}Am. But, for the dating of recent sediments, ^{210}Pb (100 to 150 years BP) and ^{137}Cs (post 1954) are widely used.

4.5.1 ^{210}Pb Dating technique

This method is very popular and has been applied in several lake studies, the world over. The applications of ^{210}Pb dating are many and varied. A sediment core records a detailed history of the environment in its vicinity and the ^{210}Pb dating technique provides a chronology covering a time scale of 100-150 years, uniquely suited to the period of man's greatest impact.

The basic principle is discussed below in brief. In uranium (^{238}U) decay series, radium (^{226}Ra)

emits radon (^{222}Rn) that escapes into the atmosphere. Further decay of radon gives rise to ^{210}Pb and other short lived daughter products in the atmosphere which are removed through aerosols by dry fallout and precipitation. The decay chain of ^{238}U is given below with the half lives of decay products.

$$^{238}U \;\underset{4.5\times 10^{9}\text{ a}}{\rule{3em}{0.4pt}}\; ^{226}Ra \;\underset{1620\text{ a}}{\rule{3em}{0.4pt}}\; ^{222}Rn \;\underset{3.8\text{d}}{\rule{3em}{0.4pt}}\; ^{218}Po \;\underset{3.05\text{ m}}{\rule{3em}{0.4pt}}\; ^{214}Pb \;\underset{26.8\text{ m}}{\rule{3em}{0.4pt}}\; ^{214}Bi$$

$$\Big|\; 26.8\text{ m}$$

$$(\text{Stable})\; ^{206}Pb \;\underset{138\text{d}}{\rule{3em}{0.4pt}}\; ^{210}Po \;\underset{3.8\text{d}}{\rule{3em}{0.4pt}}\; ^{210}Bi \;\underset{22.26\text{ a}}{\rule{3em}{0.4pt}}\; ^{210}Pb \;\underset{1.6\times 10^{-4}\text{ s}}{\rule{3em}{0.4pt}}\; ^{214}Po$$

where a is time (years); m is time (months); d is time (days); and s is time (seconds).

The residence time for ^{210}Pb in the lower atmosphere is less than a week (Poet et al., 1972). The ^{210}Pb flux from atmosphere to land and water surfaces is a continuous process. In other words, most of the ^{210}Pb entering the surface water bodies comes from direct atmospheric input across the surface. They may also find their way through indirect atmospheric fall-out or by radon decay in water body (Eakins, 1983). The ^{210}Pb thus entering the lake is removed rapidly by suspended particulate matter and accumulate as lake sediments. This ^{210}Pb is termed as unsupported ^{210}Pb or ^{210}Pb excess. However, since ^{210}Pb is also produced insitu (supported ^{210}Pb) as a result of the decay of terrigenous ^{226}Ra present in the lake sediments, the activities of both supported as well as unsupported ^{210}Pb must be known for using the technique.

The ^{210}Pb activity is measured either through direct beta-counting or through the alpha-counting of its grand-daughter, namely ^{210}Po, which is assumed to be in secular equilibrium with its parent. Direct beta-counting of ^{210}Bi involves radiochemical separation of lead by leaching with HBr, extracting with toluene followed by anionic exchange step and re-extraction with dilute HCl. This Pb is then dissolved in HNO_3 and mixed with suitable cocktail to measure the activity using a Liquid Scintillation Counter (Kulzer et al., 1994). However, the alpha-counting of the grand-daughter product (^{210}Po) is more widely used. In this case, the basic radiochemical procedure involves adding of ^{209}Po as a yield tracer, leaching the sediment samples with aqua regia, filtering off the residual solids and converting to chloride with concentrated HCl. The final solution is taken in 0.5 M HCl. Polonium nuclides are then spontaneously deposited on silver planchette by adding ascorbic acid in the HCl solution prior to alpha counting using silicon surface barrier detector connected to a multi-channel analyser. As the supported ^{210}Pb results from the decay of ^{226}Ra present in the sediment core with which it is in equilibrium, ^{226}Ra activity is determined directly (discussed below) by gamma counting.

The ^{210}Pb activity interpretation involves certain assumptions and can be approached by adopting any of the following three different models that are widely used for dating ^{210}Pb deposits with / without significant mixing during deposition: (a) Constant Initial Concentration [CIC], (b) Constant Flux [CF] and (c) Constant Flux and Constant Sedimentation Rate [CFCS](Krishnaswami and Lal, 1978; Crickmore, et al. 1990). However, none of the above model is universally applicable. In practice, the type of model to be used is usually decided on the depth-wise distribution of total ^{210}Pb concentration (Crickmore et al., 1990).

4.5.2 ^{137}Cs Method for sediment dating

^{137}Cs is produced in the atmosphere due to cosmic ray interactions. However, its concentration increased many folds in the atmosphere due to the test of nuclear weapons and since 1954, it has been globally detectable. ^{137}Cs is strongly absorbed on tiny particles like clay materials, silts and humic materials. Surface soils with an adsorptive capacity will have a ^{137}Cs content and therefore be able to act as a self tracer. In a catchment, accumulation of a sediment layer in a lake is a measure of its trap efficiency. A comparison of ^{137}Cs of catchment soils with that of associated lake sediment shows a pronounced build up of the latter. The rates of sedimentation can be calculated from the depths of two principal time horizons, i.e., 1954 and 1964 , in the ^{137}Cs concentration profile. Presently, this has been considered as more reliable technique for the dating of sedimentation rate in past 40 years.

Temporal variations in ^{137}Cs fallout

The principal sources of information on ^{137}Cs levels in fallout are the various reports of measurements from a global network of monitoring stations (Cambray et al., 1980; US Health and Safety Laboratory, 1977). Supplementary sources include reports on individual national measurements (Bonnyman et al., 1972; Baltakmens and Gregory, 1977). The pattern of annual deposition at Australian stations has found the following principal features:

(i) first appearance of ^{137}Cs in 1953/54 and second of significant amount in 1957/58;
(ii) maximum fallout in 1963/64;
(iii) marked decrease in rate of deposition from 1959 until 1962, which appears as a minor maximum; and
(iv) considerable fallout in 1978-79 and 1986 due to Lopnor atomic test in Chaina and Chernobyl accident in Russia.

It is known that uptake of fallout by soils and sediments is rapid (Eyman and Kevern, 1975), and it follows that surface soil minerals have been labelled continuously at levels which depend on the prevailing concentration of ^{137}Cs in the total fallout. It must be remembered, however, that after the peak in fallout the integrated source function of ^{137}Cs does not follow the pattern of atmospheric fallout which has decreased dramatically. Processes resulting from the overlaying of an original 1954 interface with sediment material lead to the formation of a ^{137}Cs concentration profile that relates to the annual variations in atmospheric fallout. The preservation of these structured concentration changes provides at least two time markers (dates of first appearance and maximum fallout) that are the basis of an absolute geochronology of these sediments.

Measurement of sediment redistribution with ^{137}Cs

The transport and spatial distribution of sediments entering an impoundment are functions of the balance between the flow velocities, gravitational forces and the secondary forces of flow turbulence. In the case of reservoirs, drawdown procedures can be a very powerful initiator of sediment flows and redistribution. Three generalised zones of sedimentation are given for reservoirs (Wiebe and Drennan, 1973; for sedimentary process in lakes, see Sly, 1978):

(i) The upper zone in which complex deltas form as a result of flows entering the reservoir retaining their identity for some distance into the reservoir pool. The deltas grow outward by the formation of foreset (longitudinal flow) beds and upward through topset beds.

(ii) The intermediate zone in which the residual river velocity, waves and wave-induced currents transport and deposit most of the river's wash load, and some of the fine sediments eroded from the banks of the reservoir, to form bottom set beds of fine clays, silts and colloids.

(iii) The lower zone containing sediments eroded from the reservoir banks and transported by waves and wave-induced currents.

The relevance of these sediment classifications can be seen in the work of Simpson et al. (1976) in the Hudson River estuary, New York. They were able to classify three main types of distribution of ^{137}Cs in estuary sediment cores:

(a) Relatively low activities (19 mBq/g) generally confined to the upper 5-10 cm of sediment and associated with subtidal banks.

(b) Higher activities than in (a) of about 90 mBq/g in the top 10 cm decreasing rapidly to about 7 mBq/g in the 10-15 cm layer and sometimes distributed down to 40 cm with an activity of about 1 mBq/g. This type of profile was interpreted as being indicative of a high sedimentation rate in a shallow protected environment.

(c) Profiles with variable but high activities of about 70 mBq/g down to 40 cm and, in one case, down to 250 cm. ^{137}Cs activity below 40 cm was stated by Simpson et al. (1976) to be a clear indicator of rapid sediment accumulation. It is speculated that temporal changes in ^{137}Cs profiles along a transact at each of the three zones could be interpreted as changes due to redistribution or accretion in exactly the same way that McHenry and Bubenzer (1982) interpreted changes in field distribution of ^{137}Cs.

Perhaps the best example of the potential of the ^{137}Cs technique for this type of application is the Lake Michigan (Plato and Goldman, 1972; Plato, 1974; Plato and Jacobson, 1976). The ability to interpret the structured concentration of ^{137}Cs in sediment is a very powerful aid in studying environmental influences.

Praticalities of the ^{137}Cs method

There are few details in the literature of the methods and rationale used by individual workers to obtain their samples. In taking a core sample there are three main difficulties:

(i) to avoid disturbing the very soft sediments in the upper 20 cm or so of the sedimentary sequence, yet be able to cope with a varying degree of compaction of the sediments with increasing depth (age). (The upper 20 cm region would include much of the ^{137}Cs data of interest).

(ii) to overcome suction effects during removal of the core tube from the sediment bed, or from the outer casing of the coring device; and

(iii) to avoid compression or other disturbances of the core during penetration of the core tube into the sediment bed or extrusion of the core section, which will give, rise to serious errors in an accurate determination of the sediment-water interface or the true length of the core.

A Mackereth corer (Mackereth, 1958; Mackereth, 1969) or an adaptation of its design features, would provide a good working answer to these problems. However, it requires careful handling, since its fast return to the surface can be hazardous. The core tubes range up to 1 m in length, and generally have a diameter of 5 cm. The restricted diameter means that numerous cores have to be taken at each site to accumulate sufficient material for gamma spectrometry. Ritchie and McHenry (1978) collected eight cores per site and composited them by 10 cm increments. Where it is available, clear plastic rubbing, such as polycarbonate, is to be preferred as the integrity of the core can be appraised at the surface and the coring repeated if necessary. Cores should be kept at or near in situ temperature to prevent expansion due to gas formation. Some organisations have available a cooled room for this purpose. Strong and Cordes (1976) have described a cloth sleeve filled with dry ice as a means of freezing cores. They reported that stratigraphic disturbance due to ice crystal formation did not appear to be a problem. If this or a similar cooling procedure is unavailable in the field, the cores have to be sectioned as soon as possible. An alternative to hydraulic extrusion is to section the core tube carefully along the midline to enable one half to be removed entirely. Obviously a well consolidated sediment is necessary for this technique.

Gamma spectrometry

The analysis of ^{137}Cs by gamma spectrometry, using Ge(Li) or HyperPure Ge detectors, is relatively simple. The ^{137}Cs peak has an energy of 662 keV and the only interference is from a peak at 666 keV due to ^{214}Bi. This interference can be corrected by measuring the adjacent 609.3 keV peak, which is also due to ^{214}Bi, and applying a proportional correction to the sum of the 602 and 606 peaks (McCallan et al., 1980). The net peak area is proportional to the concentration of ^{137}Cs. The US National Bureau of Standards, Research Material b, homogeneous river sediment for radioactivity measurements, is available as a primary standard. When multi-element analysis is required, ^{137}Cs, Th, U and K standards can be prepared, using trisodium phosphate (12 H_2O) as the matrix (McHenry et al., 1973).

5.0 METHODOLOGY USED FOR SAGAR LAKE

5.1 Collection of Sediment cores

The undisturbed sediment samples were collected from various locations (Fig. 3) in the lake using a gravity corer and a manually operated boat. Inner and outer diameter of the corer are 5 cm and 6 cm, respectively. Sampling locations were selected on the basis of bathymetric map and sediment entering point in the lake. Nineteen sediment cores were collected during August, 1999 from different locations and efforts were made to cover the maximum possible sedimentary environment. The length of the cores obtained ranged from 17 to 54 cm. With the help of a adjustable piston rod, the obtained cores were extruded vertically and sliced at 2 cm intervals. Sliced core sections were brought to the laboratory and were subjected to various physical and chemical processes before measuring ^{137}Cs. Bulk density was determined before drying the samples in an oven at a temperature slightly above 100°C for about 12 hours prior to analysis. The dry unit weight (expressed as the ratio of weight of dry sediment sample to total volume of the sliced core sample) of the sliced core samples including the percent of organic matter were determined. In order to measure the percent of organic matter in each 2 cm slice of sediment core, a definite amount of the core sample was burnt at 550° C for 30 minutes.

5.2 Dating of Sediment Cores

All the sliced core samples of eleven cores were powdered fine and subjected to ^{137}Cs radiometric dating as described in methodology. The ^{137}Cs activity in each section was determined by gamma counting of the oven-dried samples using Hyper Pure Germanium detector coupled with a 4096 channel multi-channel analyser system. A ^{137}Cs standard, having essentially the same geometry and density was used. About 10 gm or less (if the weight of sediment core was less than 10 gram) weight of the sliced cores were counted for about 7200 to 28800 seconds to obtain good statistical accuracy. The detection limit for ^{137}Cs by this method is 0.25 mBq/g and the standard counting error was less than 10 % in the core sections.

The determination of ^{210}Pb content is based on the alpha measurement of its grand-daughter, namely polonium (^{210}Po), which is assumed to be in secular equilibrium with its parent. The basic radiochemical procedure involves adding of ^{209}Po as a yield tracer, leaching the sediment samples with *aqua-regia*, the residual solids were filtered off and the solution was dried and converted to chloride with concentrated HCL. The final solution was taken in 0.5 N HCL. Polonium (^{210}Po) nuclides were then spontaneously deposited on silver planchettes by adding ascorbic acid in the HCL solution prior to alpha counting using Si surface barrier detectors connected to a multi-channel analyser. However, due care was given to get ^{210}Po in secular equilibrium with ^{210}Pb. The standard counting error was generally less than 10% in the upper sections of the cores and slightly higher values at the deeper sections since the counting time was kept constant for the entire core sections. As the supported ^{210}Pb results from the decay

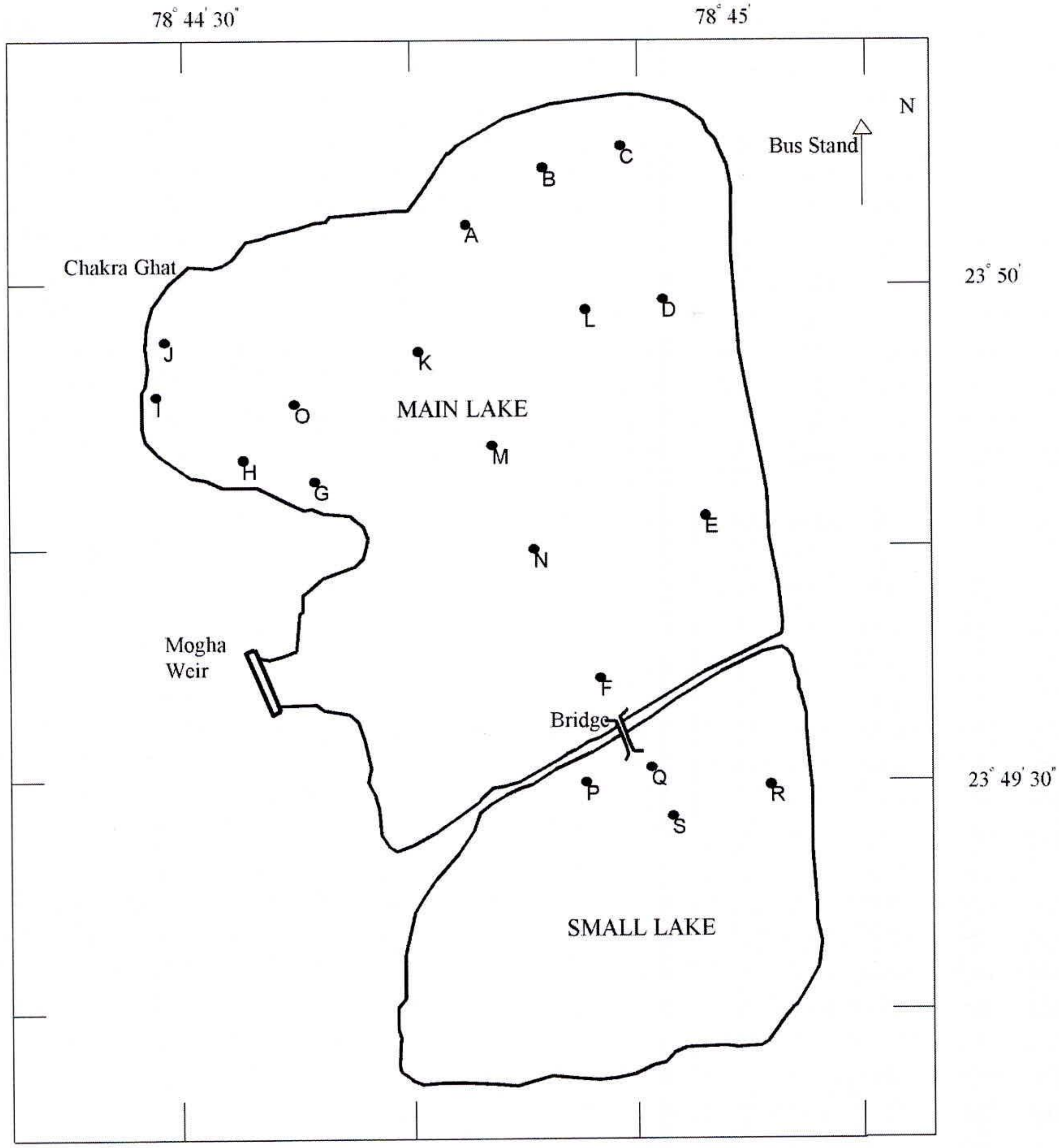


Fig. 3: Map showing sites of sediment core collected from the Sagar lake

of ^{226}Ra present in the sediment core with which it is in equilibrium, ^{226}Ra activity was determined directly by gamma counting. In the present case, the ^{210}Pb activity was also measured in terms of beta radiations using ^{210}Bi which is its daughter product and has half life of ~5 days. The extracted solution containing ^{210}Pb was allowed to stay for a period of one month (4-5 half lives are sufficient) for getting ^{210}Bi in secular equilibrium with ^{210}Pb activity. The activity of ^{210}Bi was measured using a Ultra Low level Liquid Scintillation spectrometer.

As already discussed about different models; such as Constant Rate Supply (CRS) or Constant Flux (CF) and Constant Initial Concentration (CIC) models, that are being widely used for dating ^{210}Pb deposits with/without significant mixing during deposition (Krishnaswami and Lal, 1978; Crickmore et al. 1990). However none of the models is universally applicable (Eakins, 1983; Robbins and Edgington, 1975). In practice the type of model to be used is usually decided on the depthwise distribution of (total) ^{210}Pb concentration (Crickmore et al. 1990). In the present case, CFCS model has been used for estimating rates of sedimentation.

6.0 RESULTS AND DISCUSSION

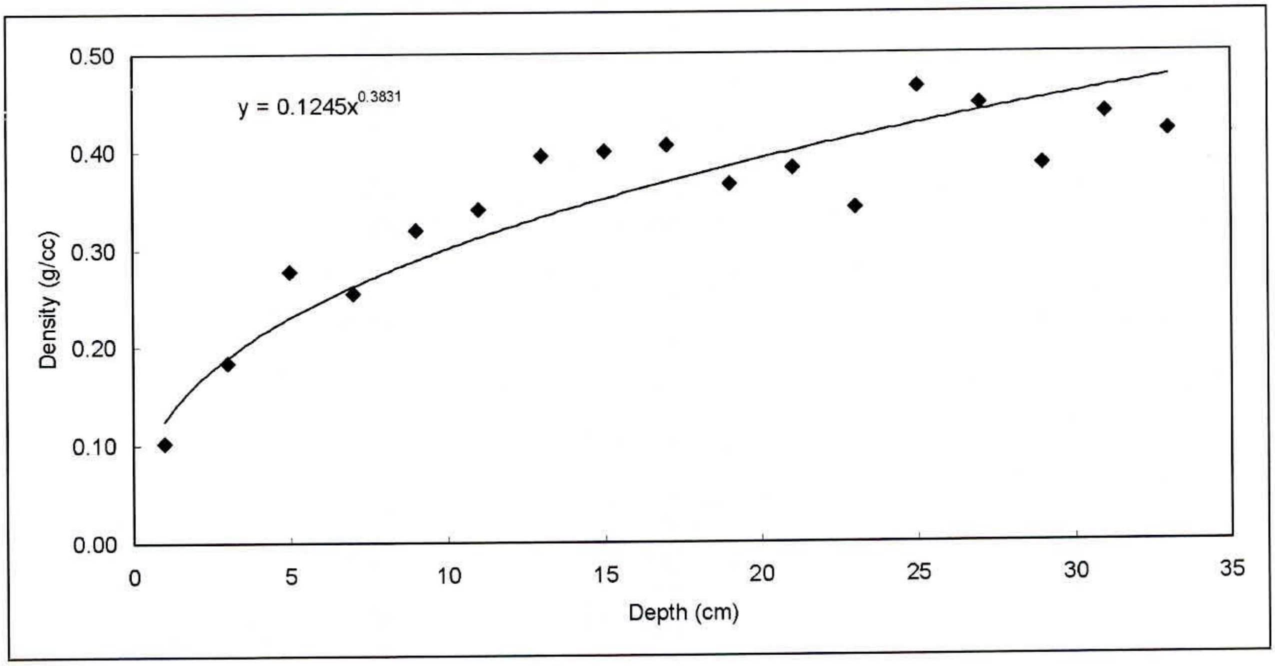
To determine the sedimentation rate of lake, samples of eleven cores were analysed using ^{137}Cs and five cores were analysed using ^{210}Pb techniques. The ^{137}Cs and ^{210}Pb activities determined in the sediment cores are shown for represented cores in the Figs. 4 to 19. The variation of dry density for various cores is presented in Figs. 4 to 14. The sediment cores collected from different locations contain organic matter in the range of 14 to 27 %. Organic matter varies between 17 to 24% in core B, 18 to 20% in core L, 14 to 24 % in core N, 18 to 27 % in core O and 14 to 17% in core P. The maximum amount of organic matter is found in core collected from north-west portion of the lake at location O. The higher percentage of organic matter lies in upper part of the sediment cores, except core O, reveals that lake is receiving more organic matter in recent years. The dry density increases with increase in depth (Fig. 4 to 14) except in core O. The core O shows nearly same dry density with increasing depth. Core O is collected from the location where lake receives city waste water from a number of small channels. The details of dry density and ^{137}Cs activity are given in (Tables 1 to 11).

The rates of sedimentation in various cores have been presented in Table 12 using ^{137}Cs and ^{210}Pb dating techniques. Sedimentation rates of 1.08 cm/y are determined in the cores collected from the western portion of the lake near Ganga Mandir. The deeper portion area of the lake is receiving the sediment at a lower rate (0.38 cm/y). Small lake and Eastern part of main lake (in front of Dufrin Hospital) are showing moderate rate of deposition (0.75 to 0.81 cm/y). In the Southern portion of the lake, sediment rates are determined using ^{210}Pb techniques. In this portion, lower sedimentation rate from core E is determined at a rate of 0.30 cm/y. The Mean sedimentation rate computed for the lake is 0.58 ± 0.02 cm/y.

Sedimentation rate in Sagar lake has been compared with the other lakes located in Kumaun Himalayas where radiometric dating techniques have been used for estimation of sedimentation rate (Table 13). Sedimentation rate in Sagar lake is higher than that of Bhimtal, Naukuchiatal, Sattal and Mansar lake but comparable to Nainital lake.

6.1 Estimated Life of Sagar Lake

As already discussed, the inflow velocity and other forces such as gravitational force and the secondary forces of flow turbulence control the spatial distribution of incoming sediments in lakes. Wiebe and Drennan (1973) and Sly (1978) recognised three generalised zones of sediment distribution and sedimentary processes in lakes. However, keeping in view the geomorphological features, underwater topography, core recovery and spatial variation of sedimentation, Sagar lake has been divided into eight zones (Fig. 20 and 21). The lake life has been estimated taking into account the sediment accumulation rates obtained in all the eight sub-basins and the volume of the lake.



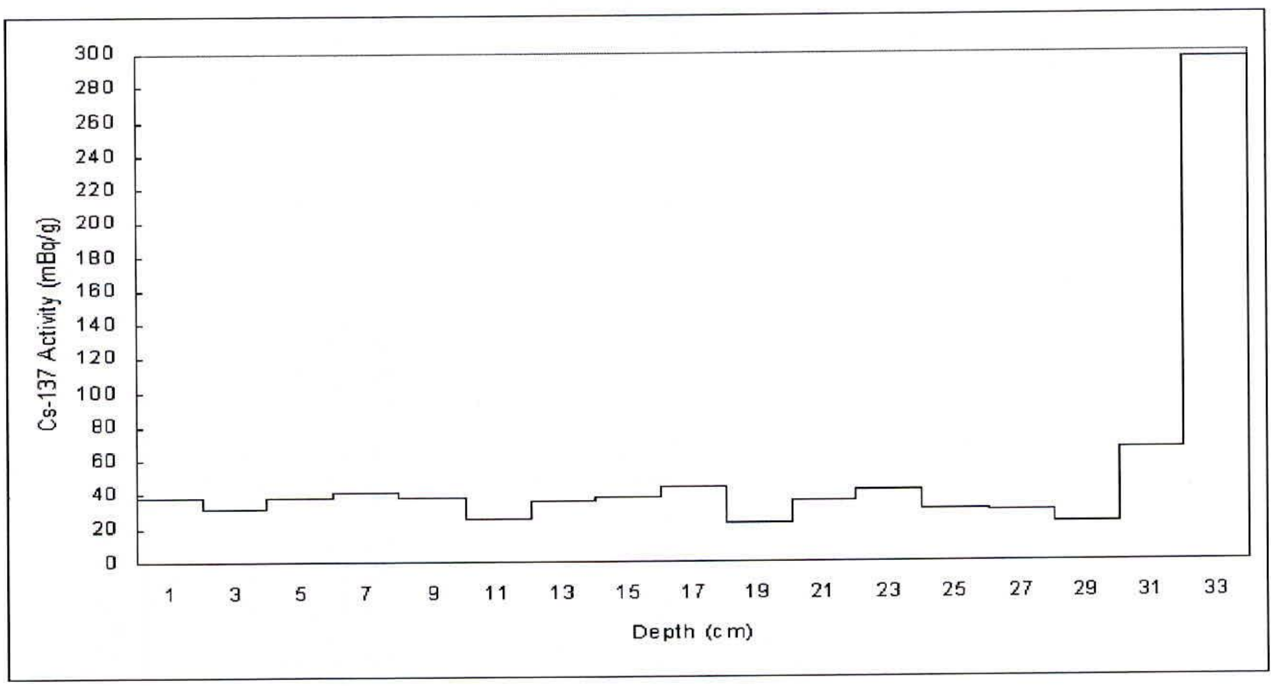
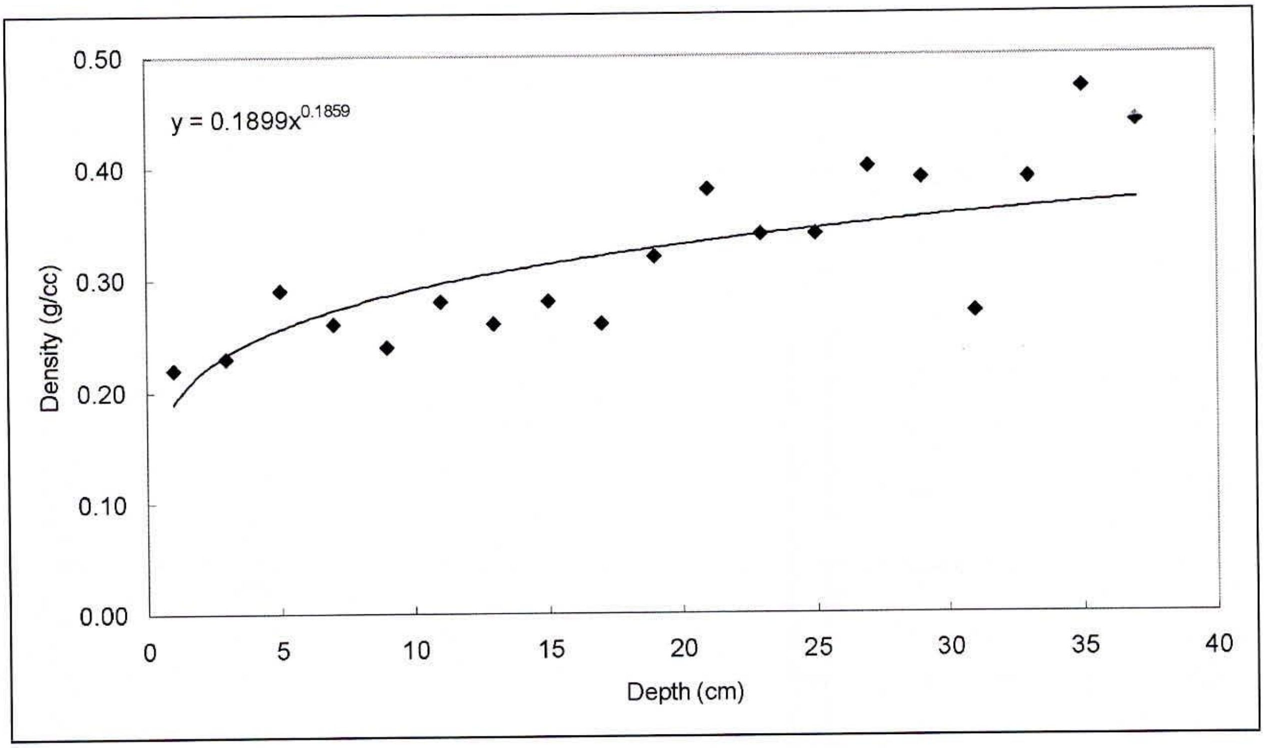


Fig. 4: Soil characteristic and dating details of Core A



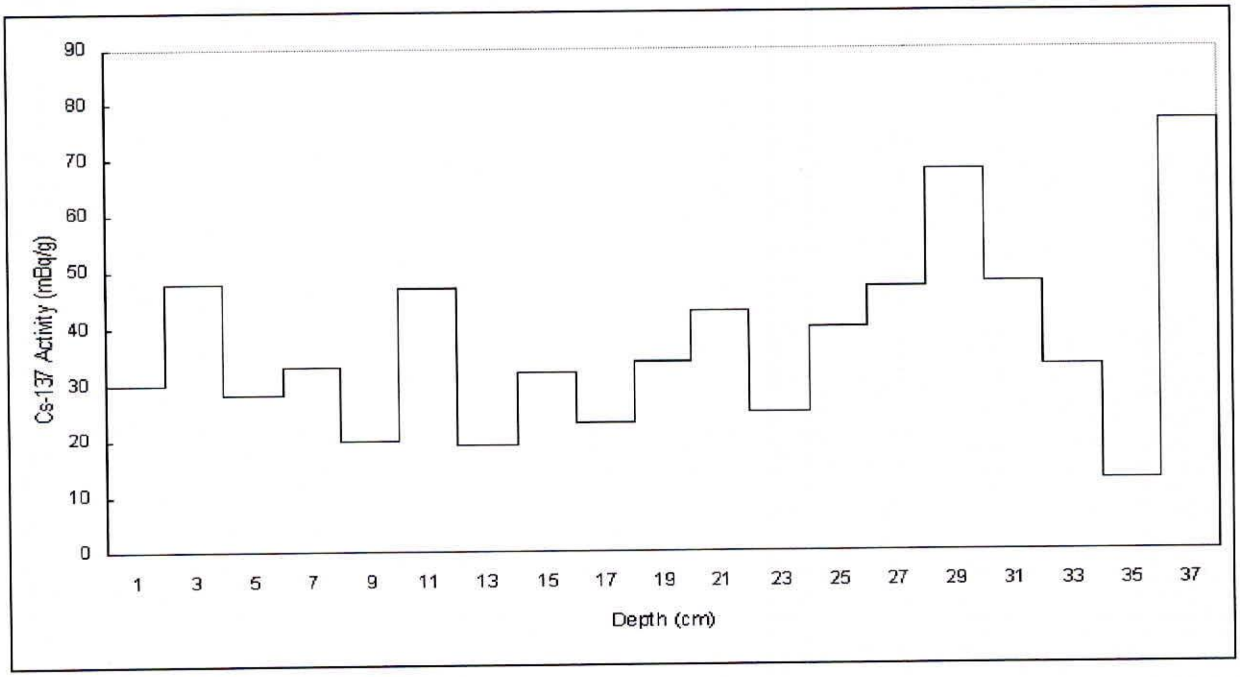
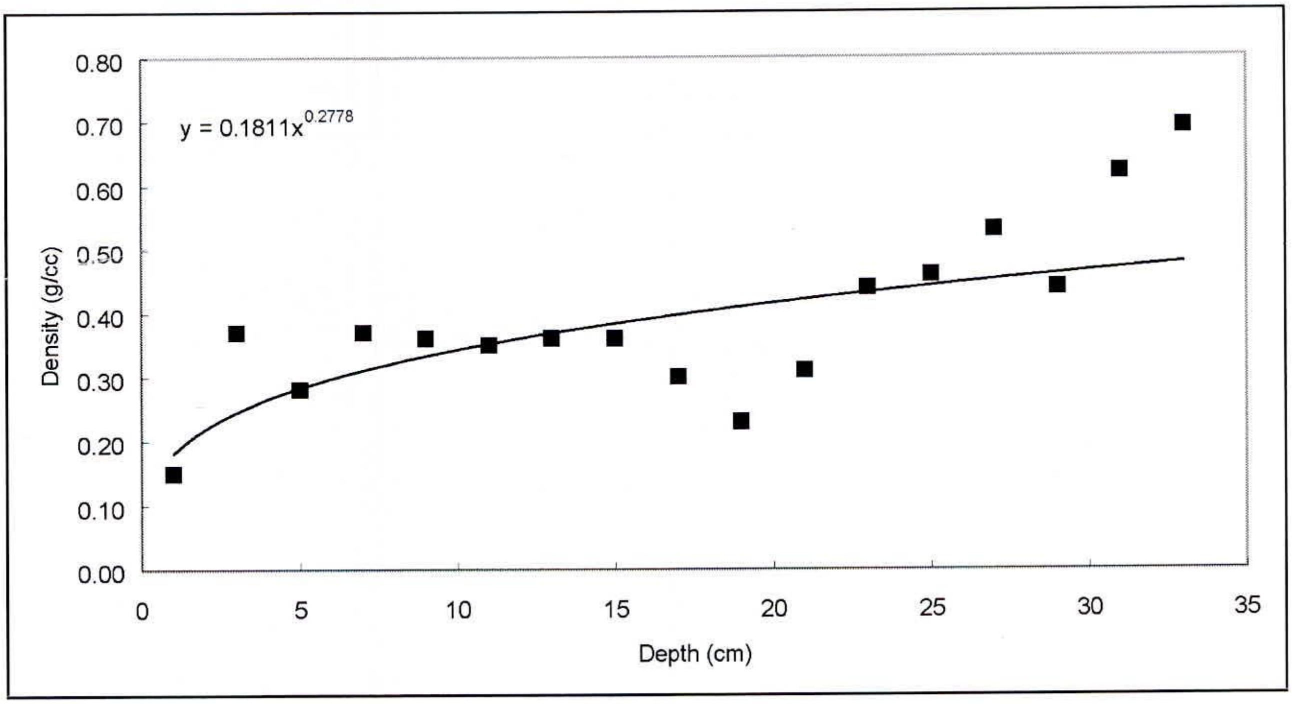


Fig. 5: Soil characteristic and dating details of Core B



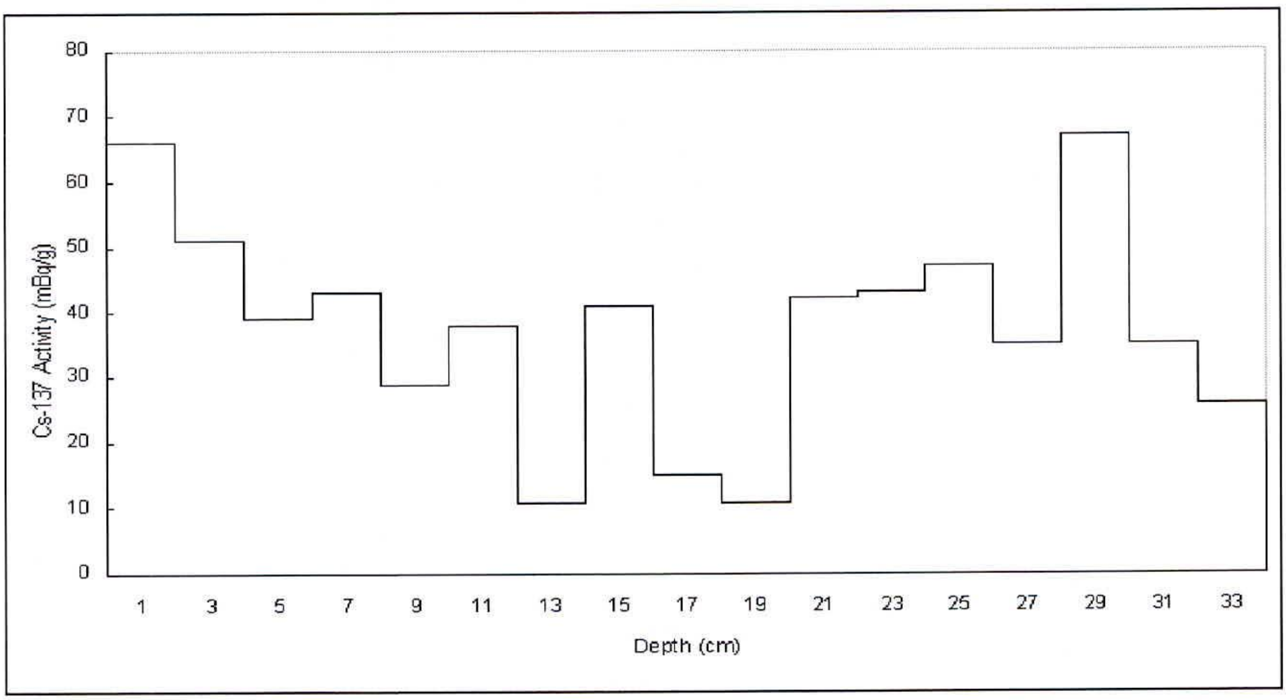
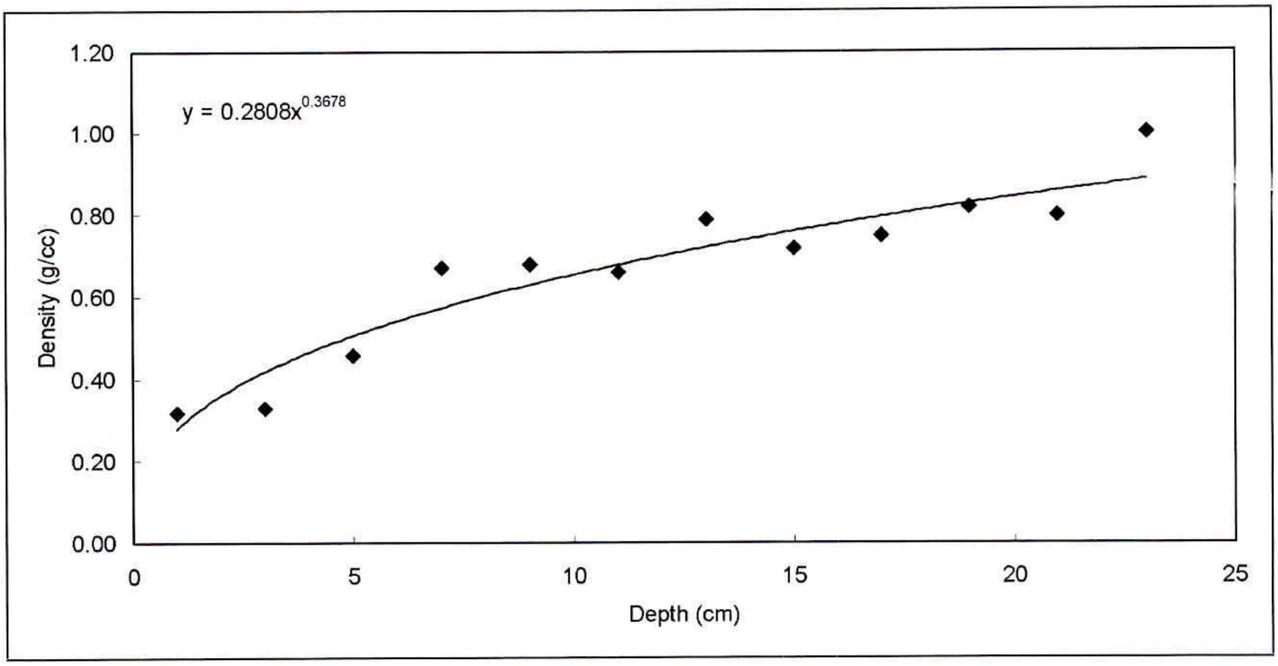


Fig. 6: Soil characteristic and dating details of Core C



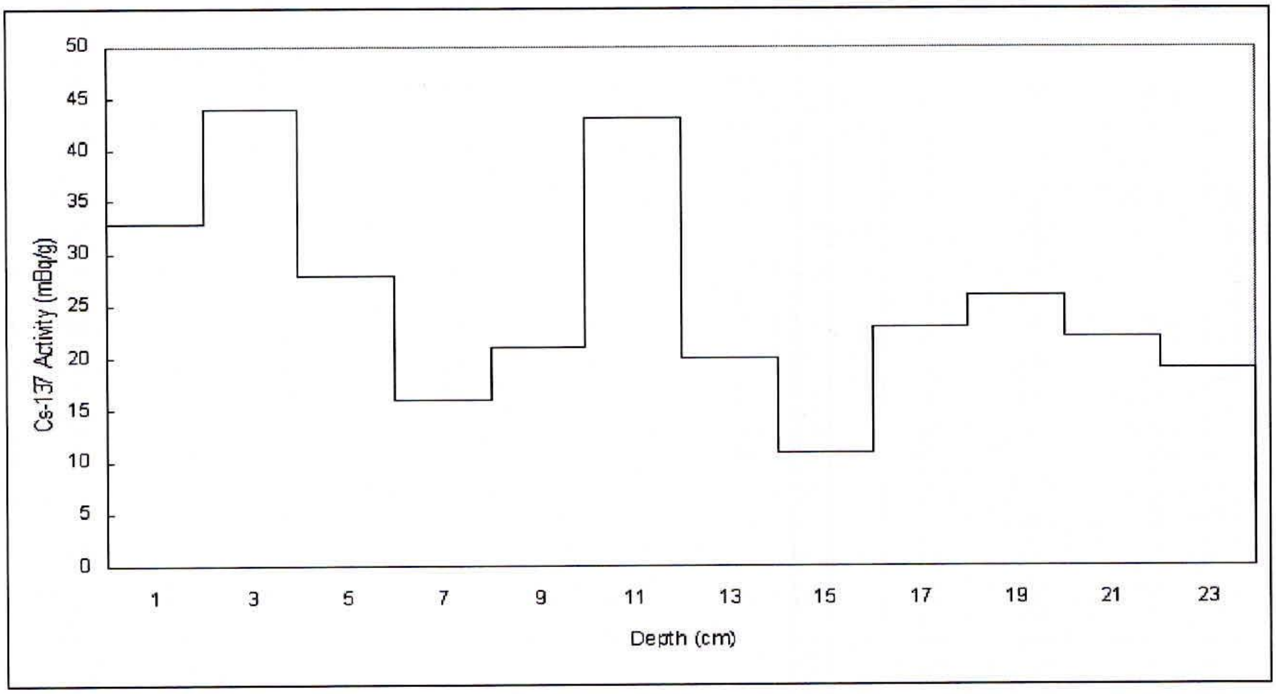
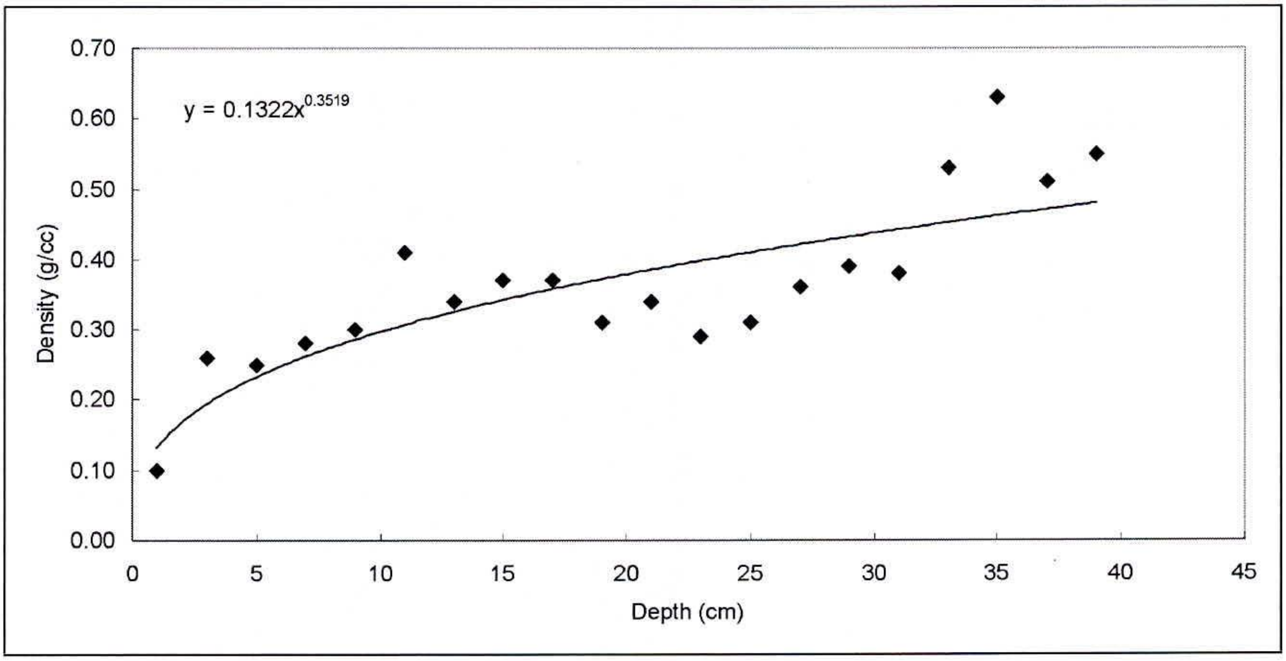


Fig. 7: Soil characteristic and dating details of Core D



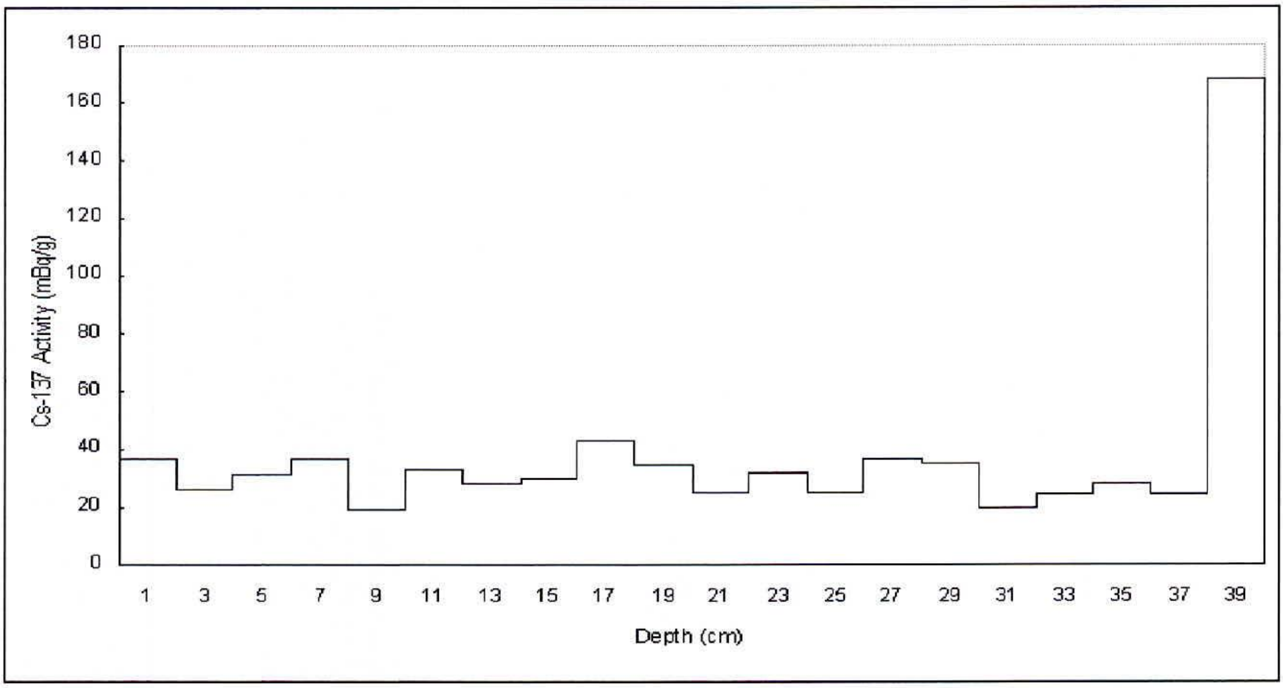
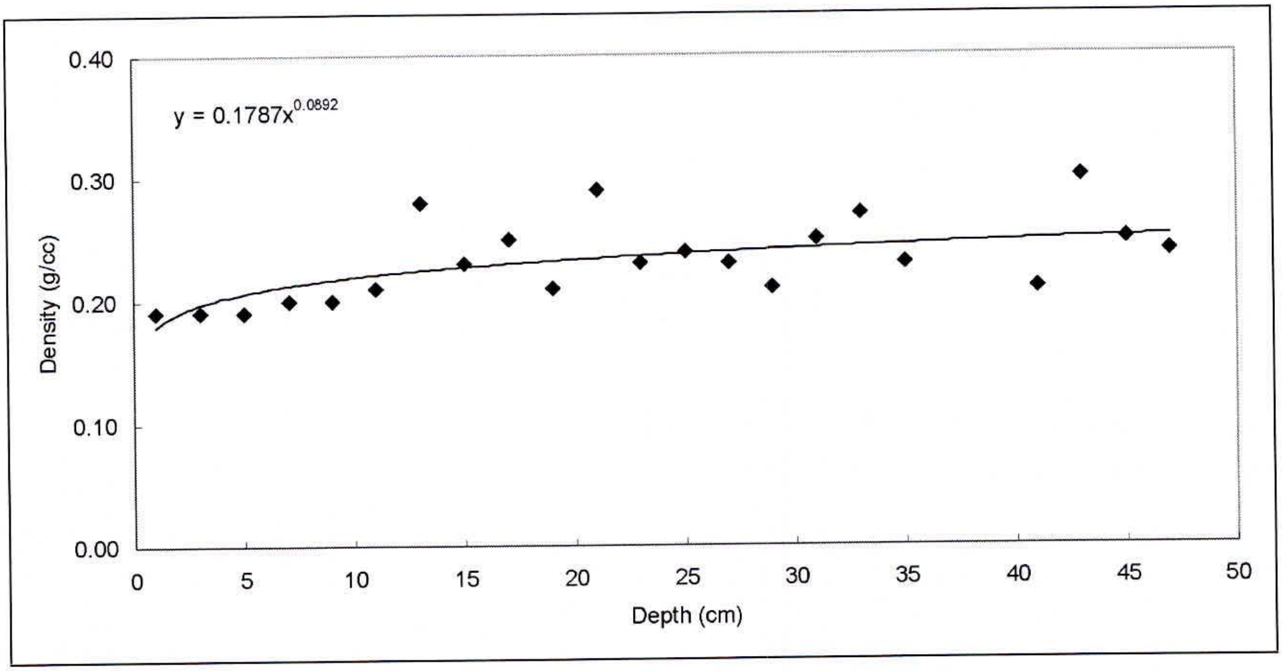


Fig. 8: Soil characteristic and dating details of Core H



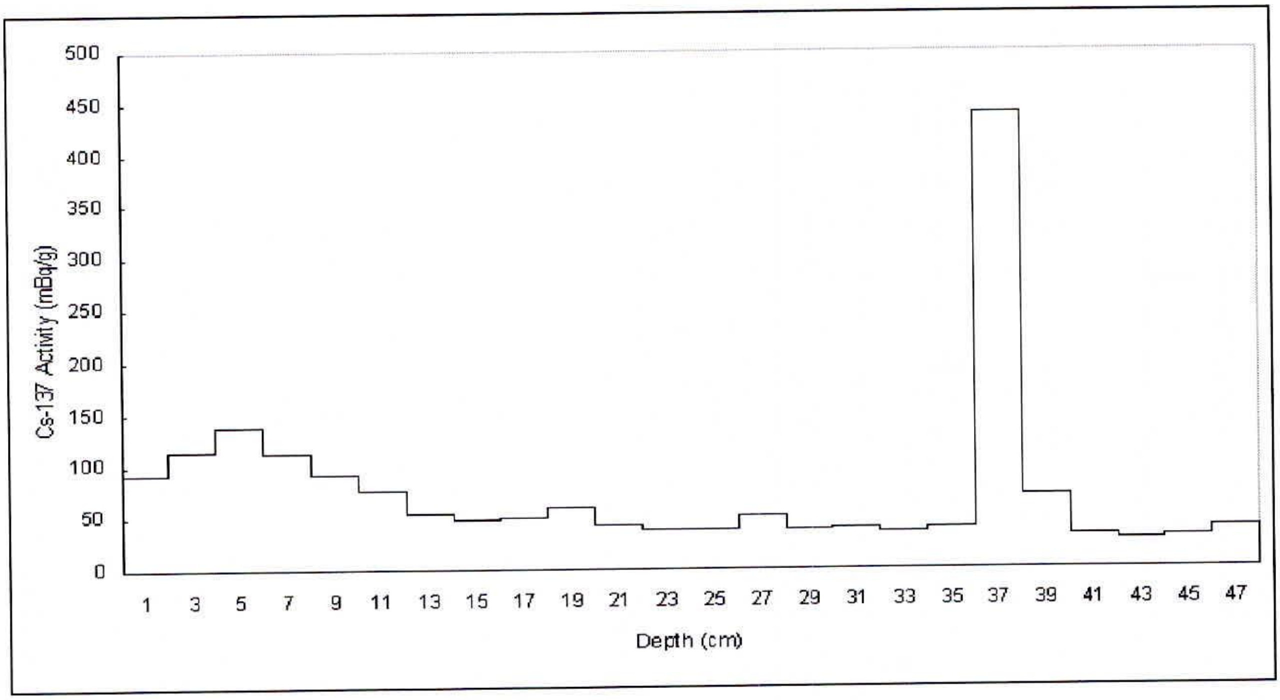


Fig. 9: Soil characteristic and dating details of Core K

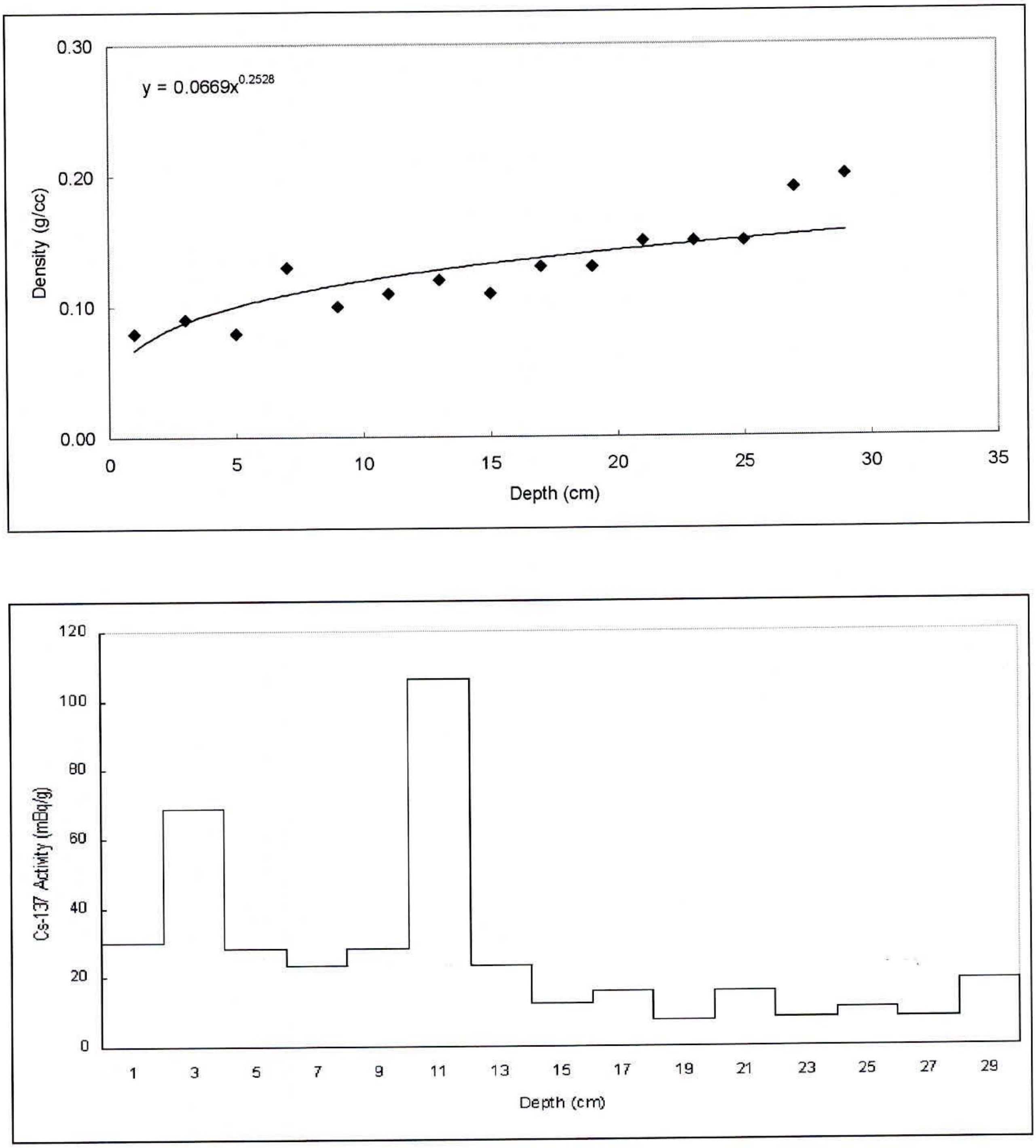


Fig. 10: Soil characteristic and dating details of Core L

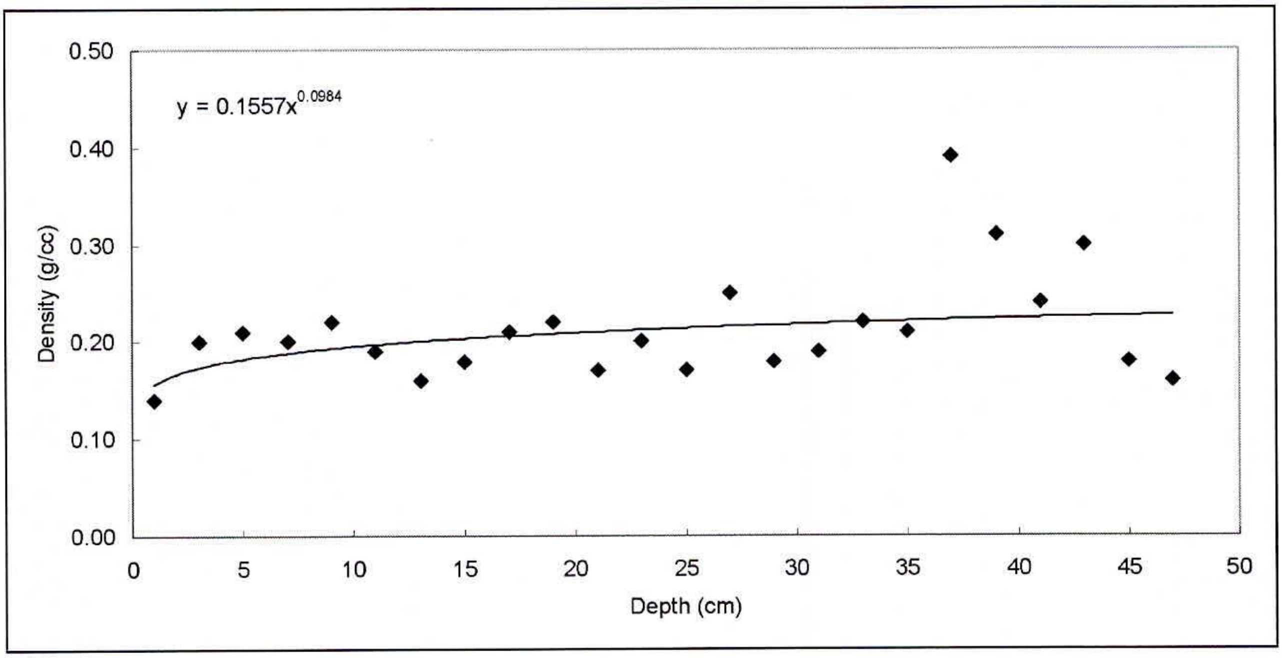
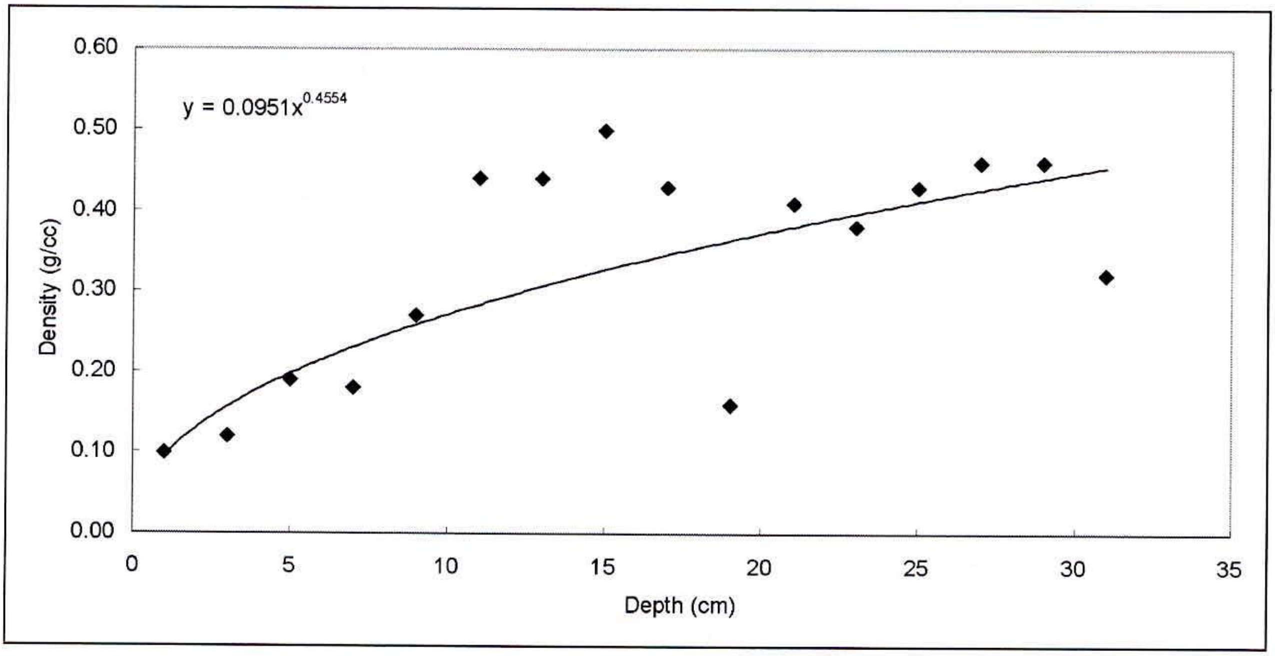


Fig. 11: Soil characteristic and dating details of Core M



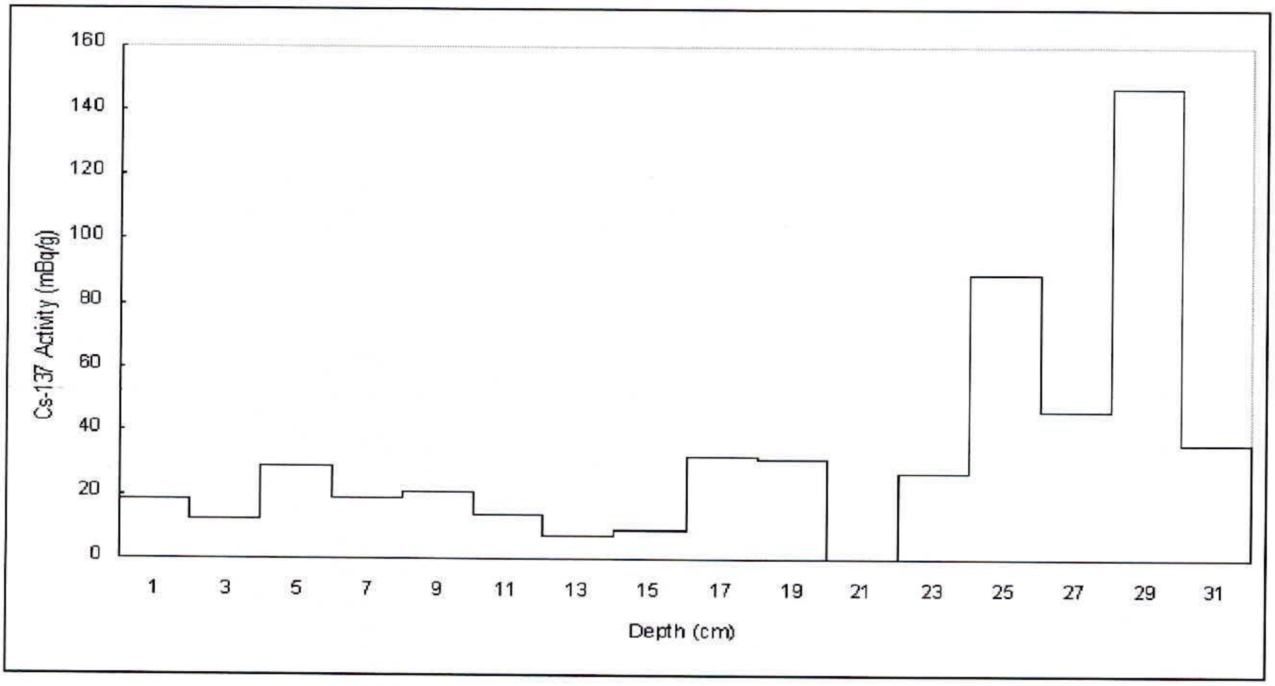
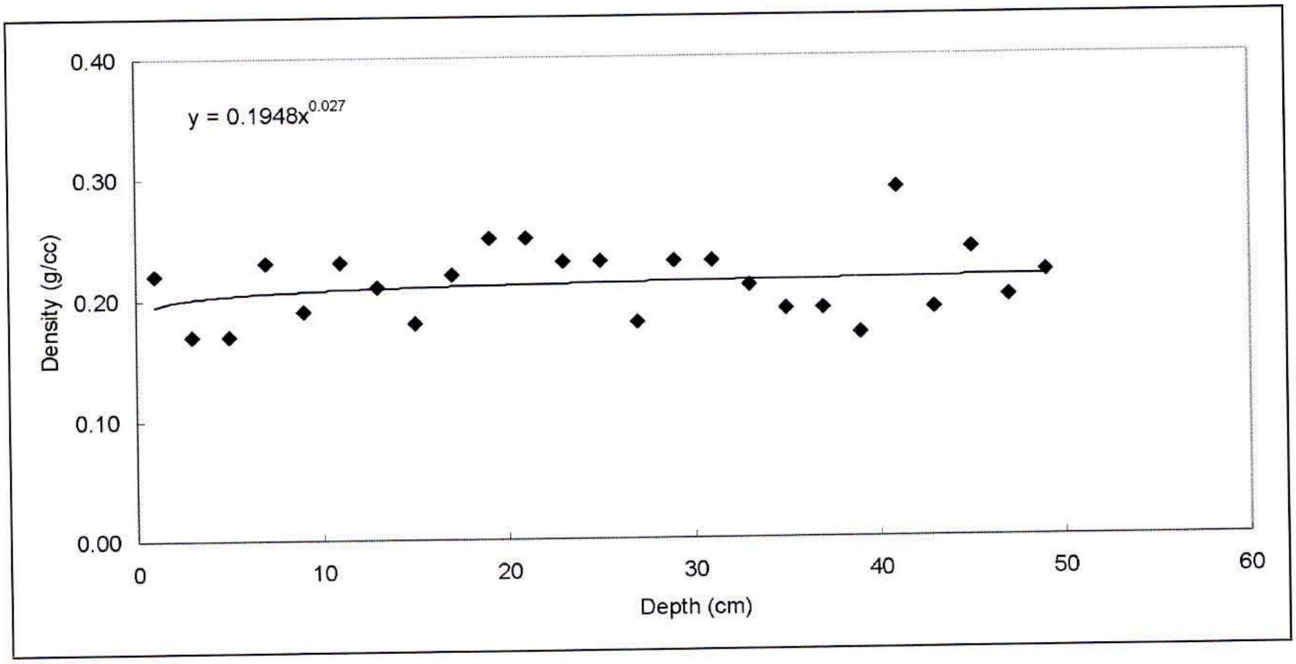


Fig. 12: Soil characteristic and dating details of Core N



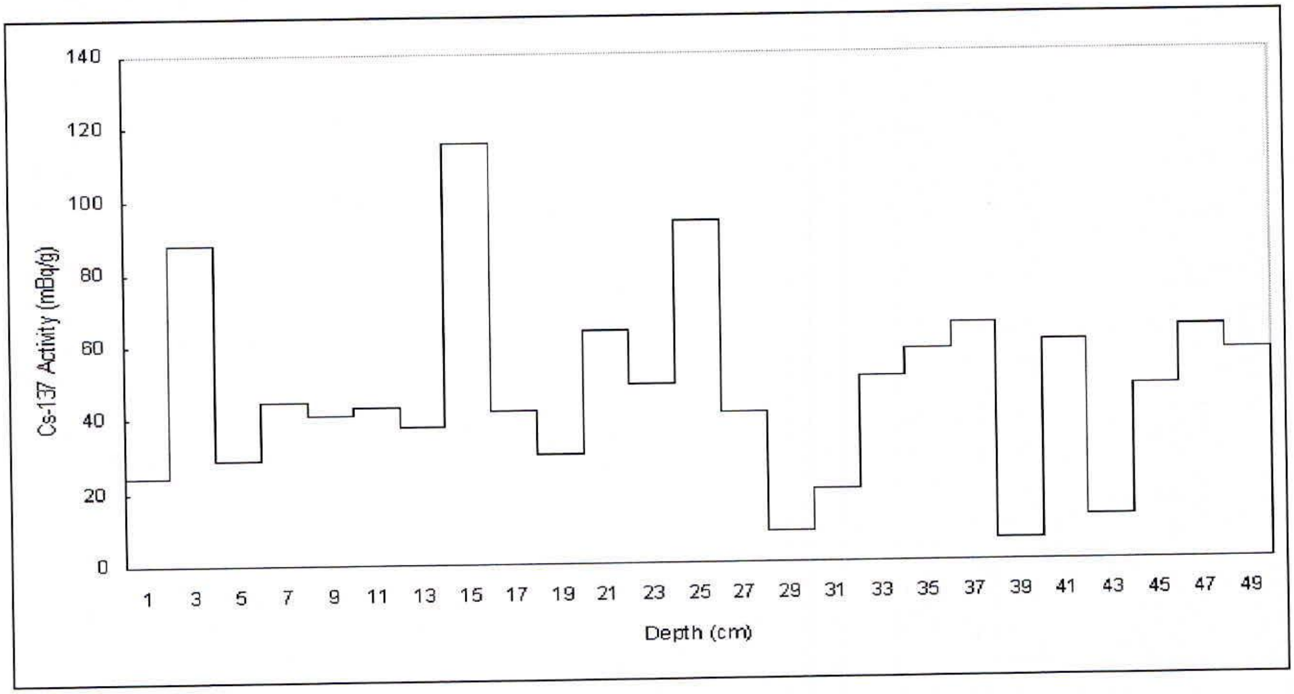
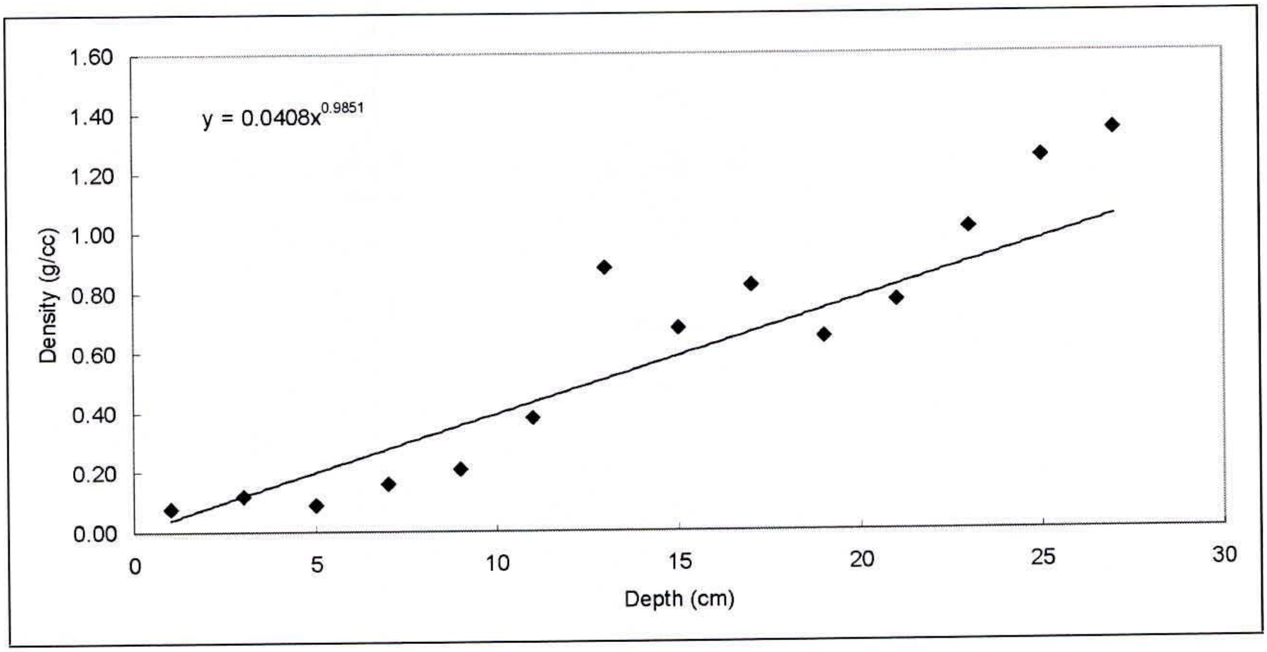


Fig. 13: Soil characteristic and dating details of Core O



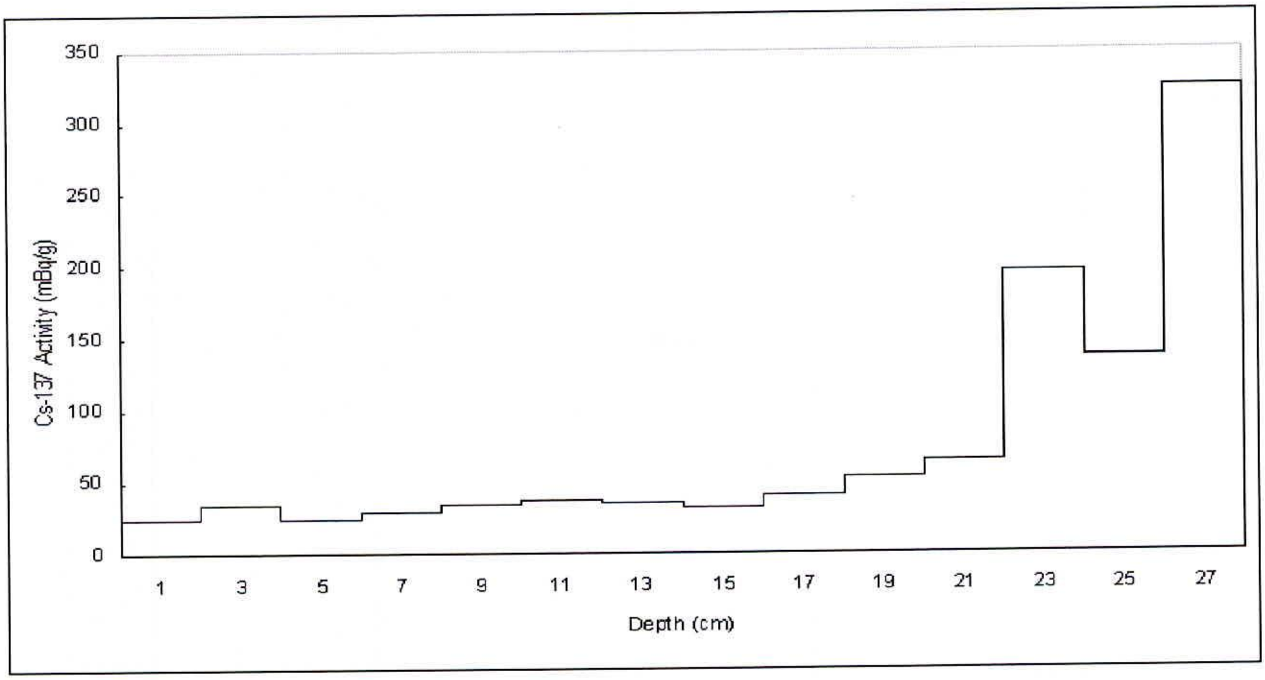


Fig. 14: Soil characteristic and dating details of Core Q

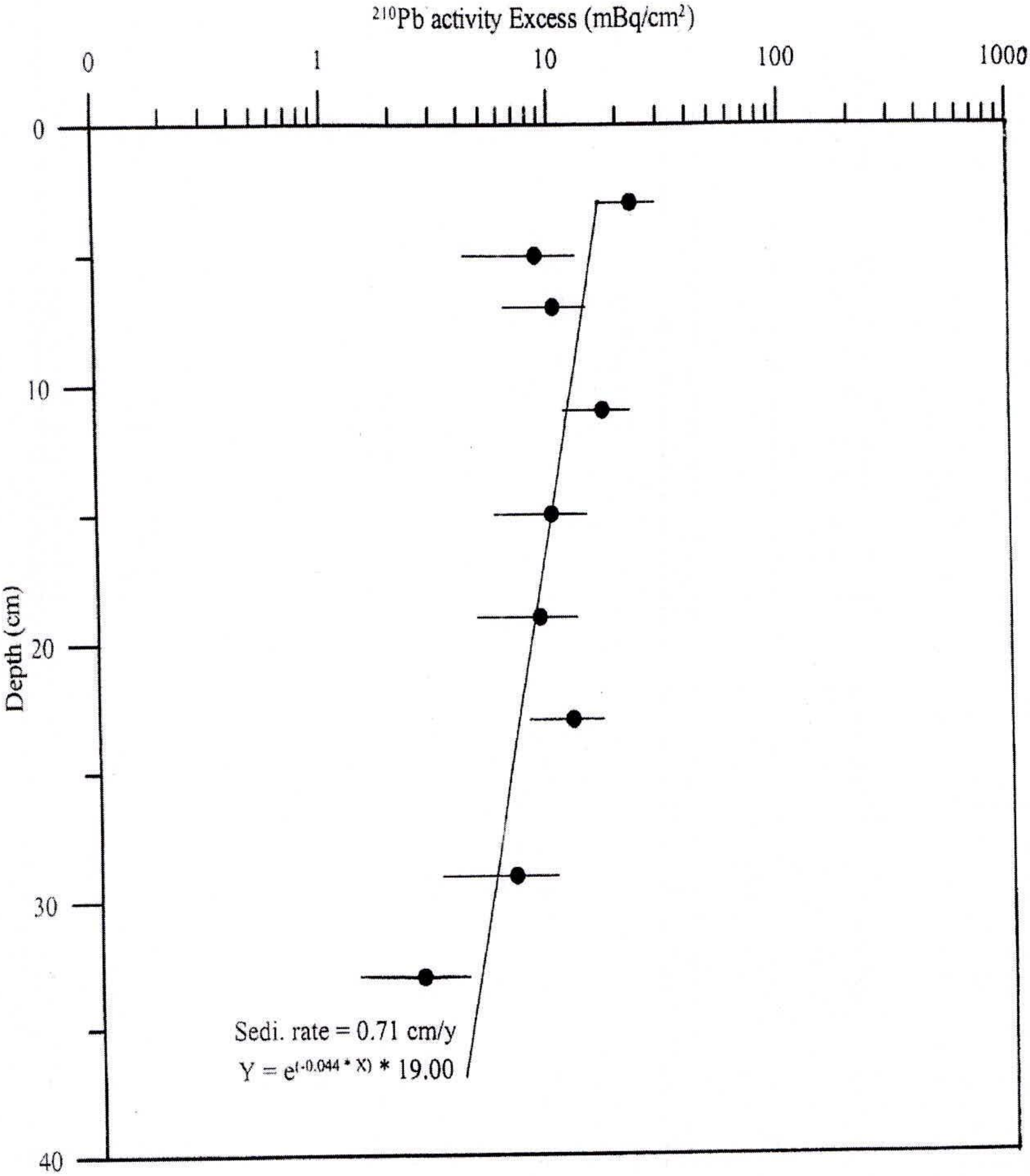


Fig. 15: ^{210}Pb activity in sediment core B

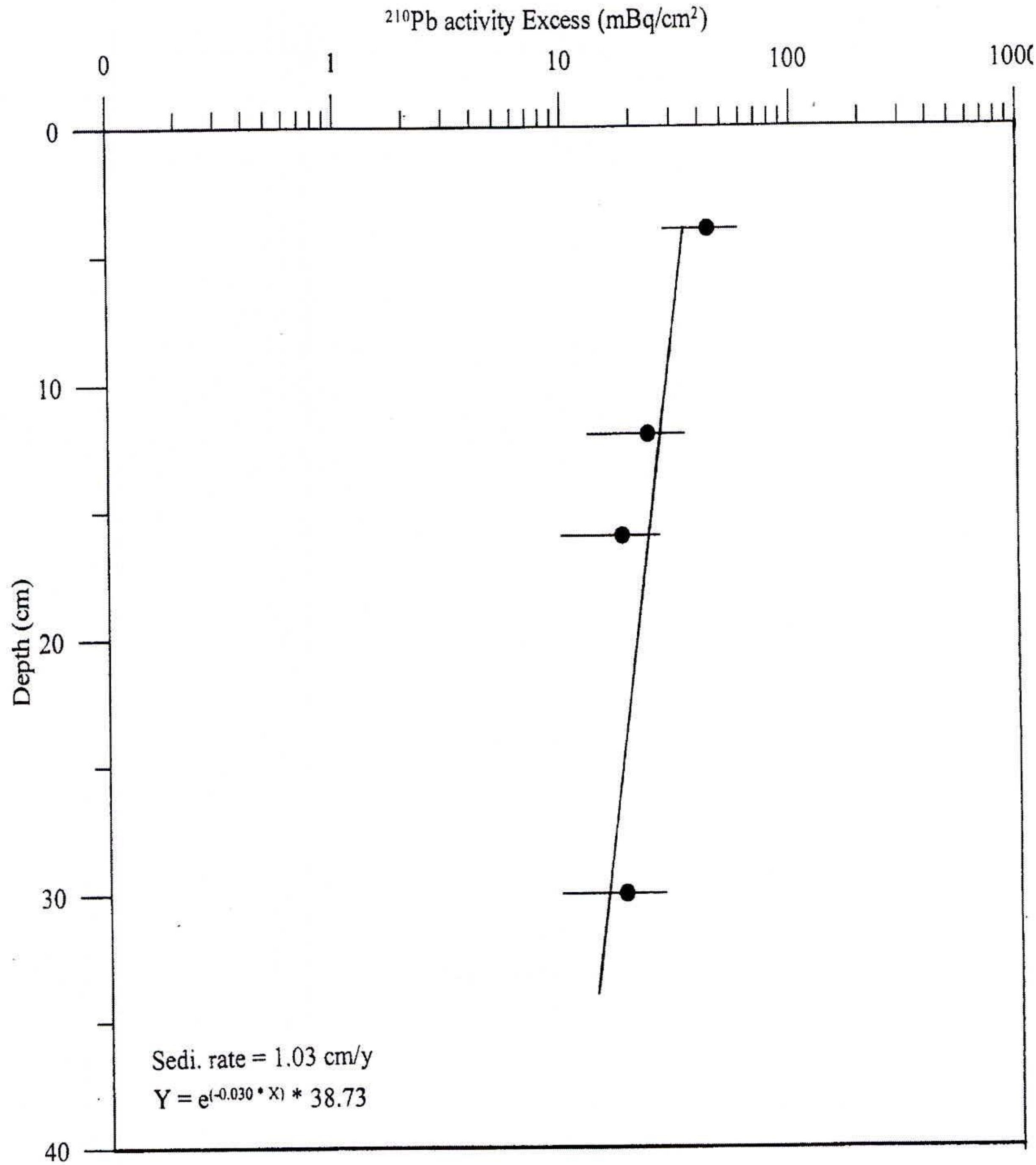


Fig. 16: ^{210}Pb activity in sediment core C

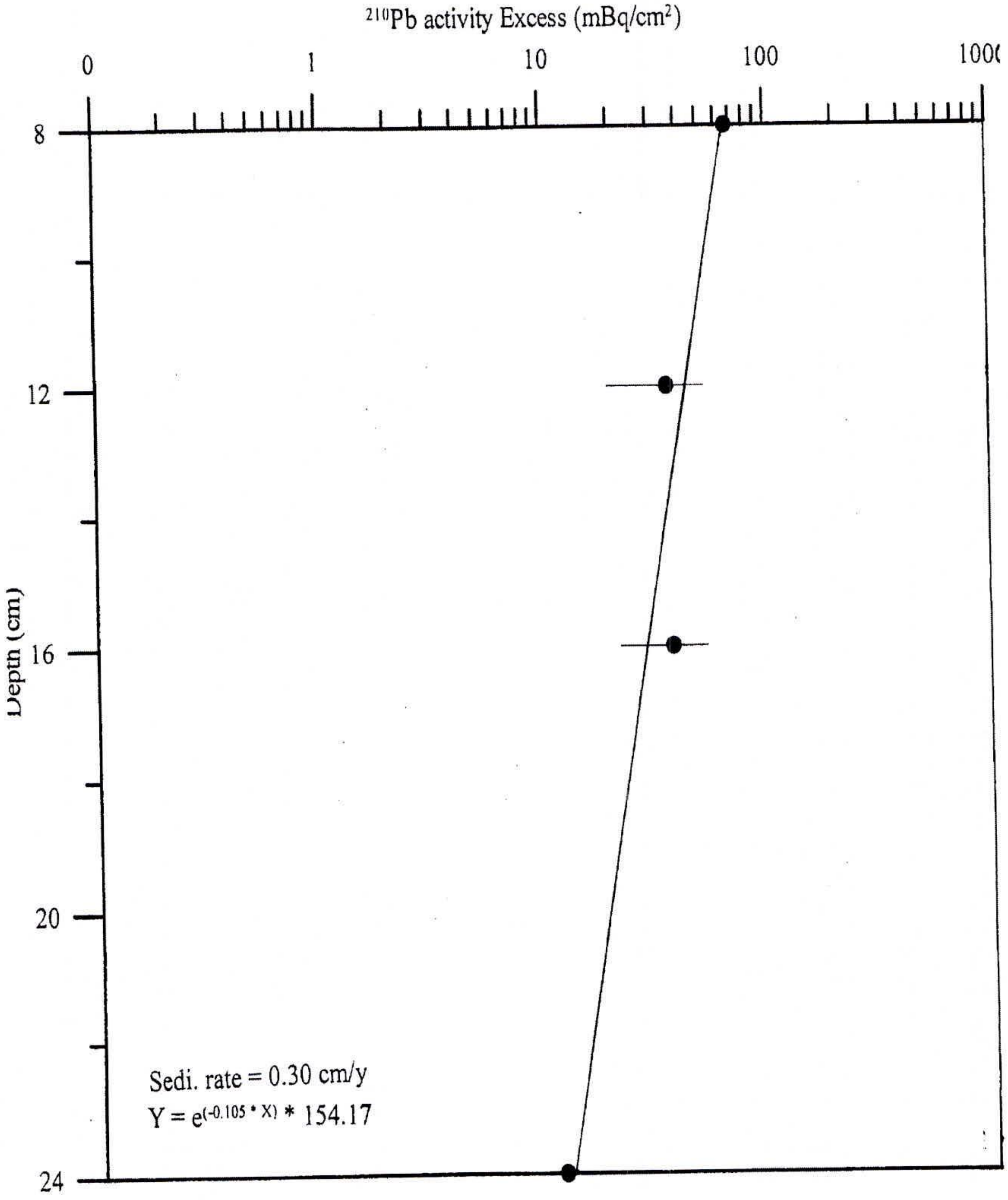


Fig. 17: ^{210}Pb activity in sediment core E

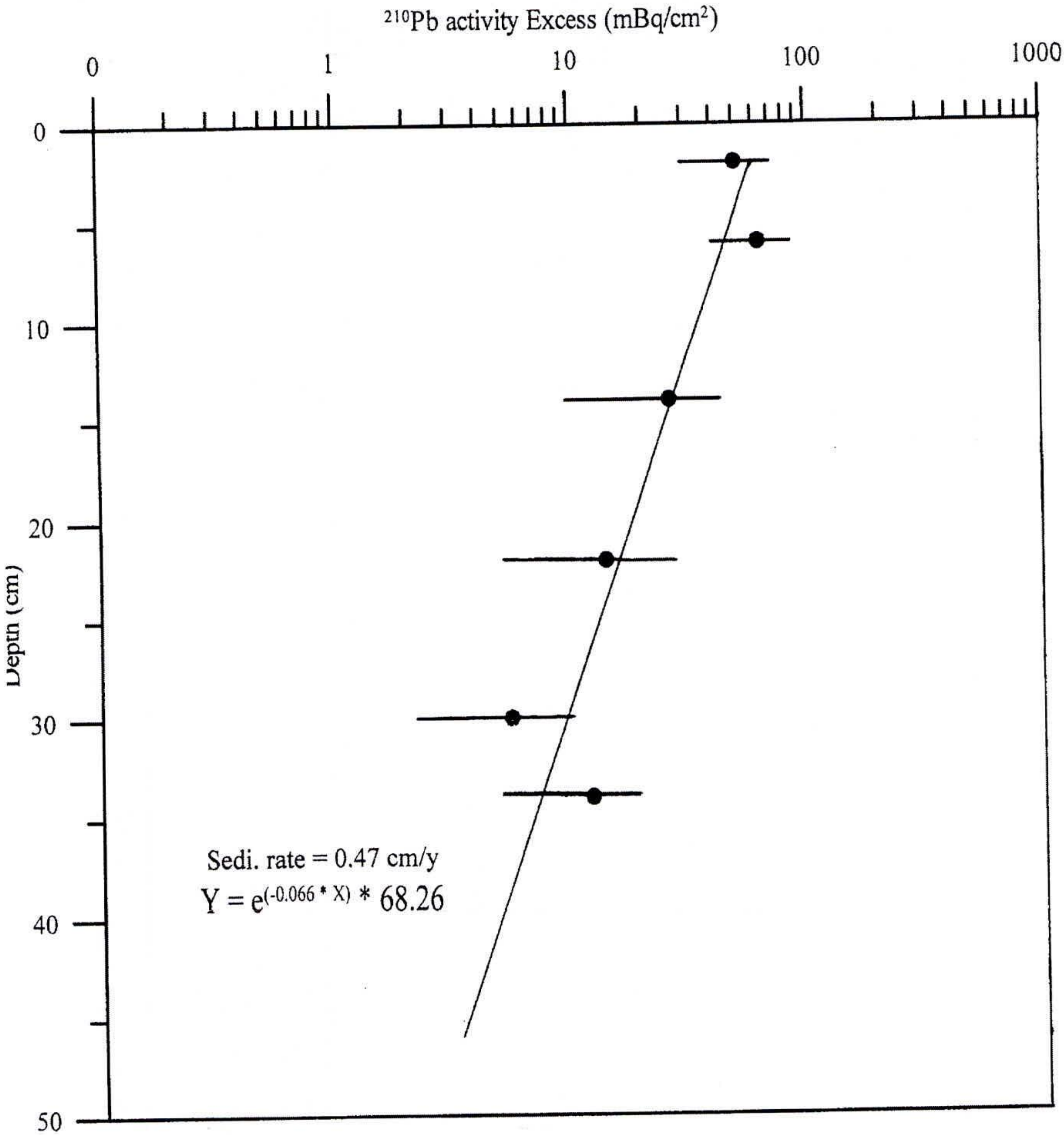


Fig. 18: ^{210}Pb activity in sediment core K

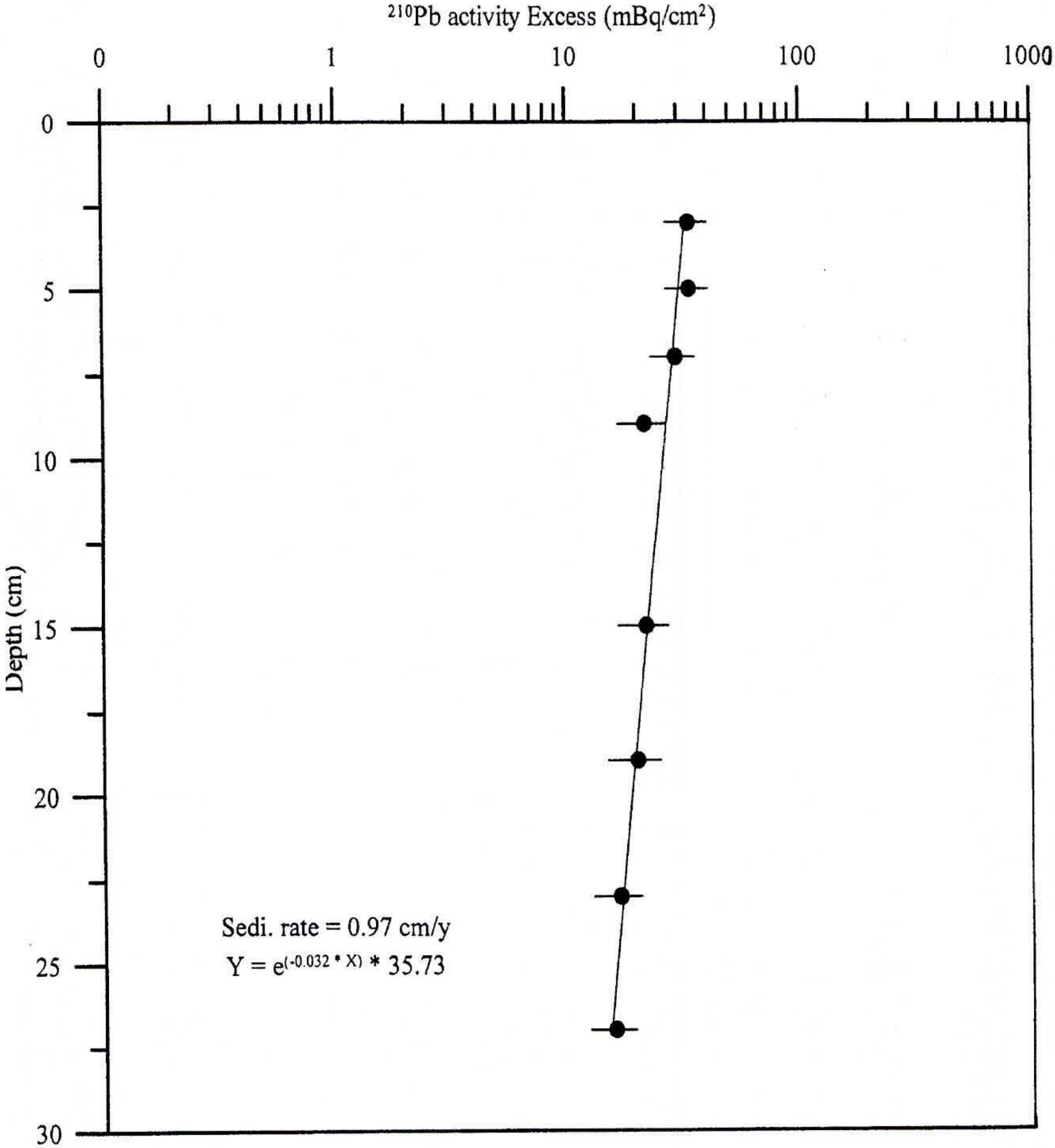


Fig. 19: ^{210}Pb activity in sediment core N

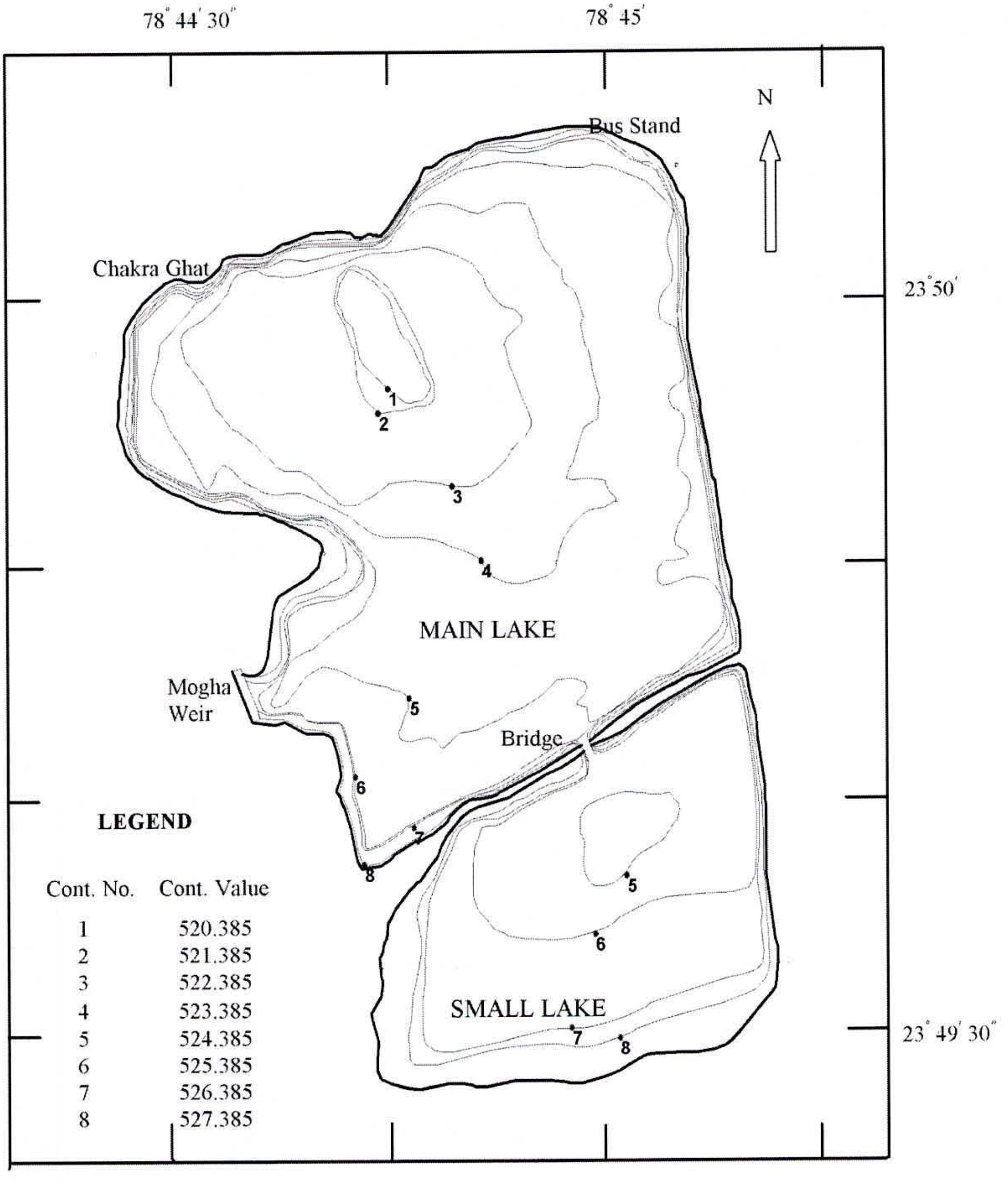


Fig. 20: Map of Sagar lake showing contour levels

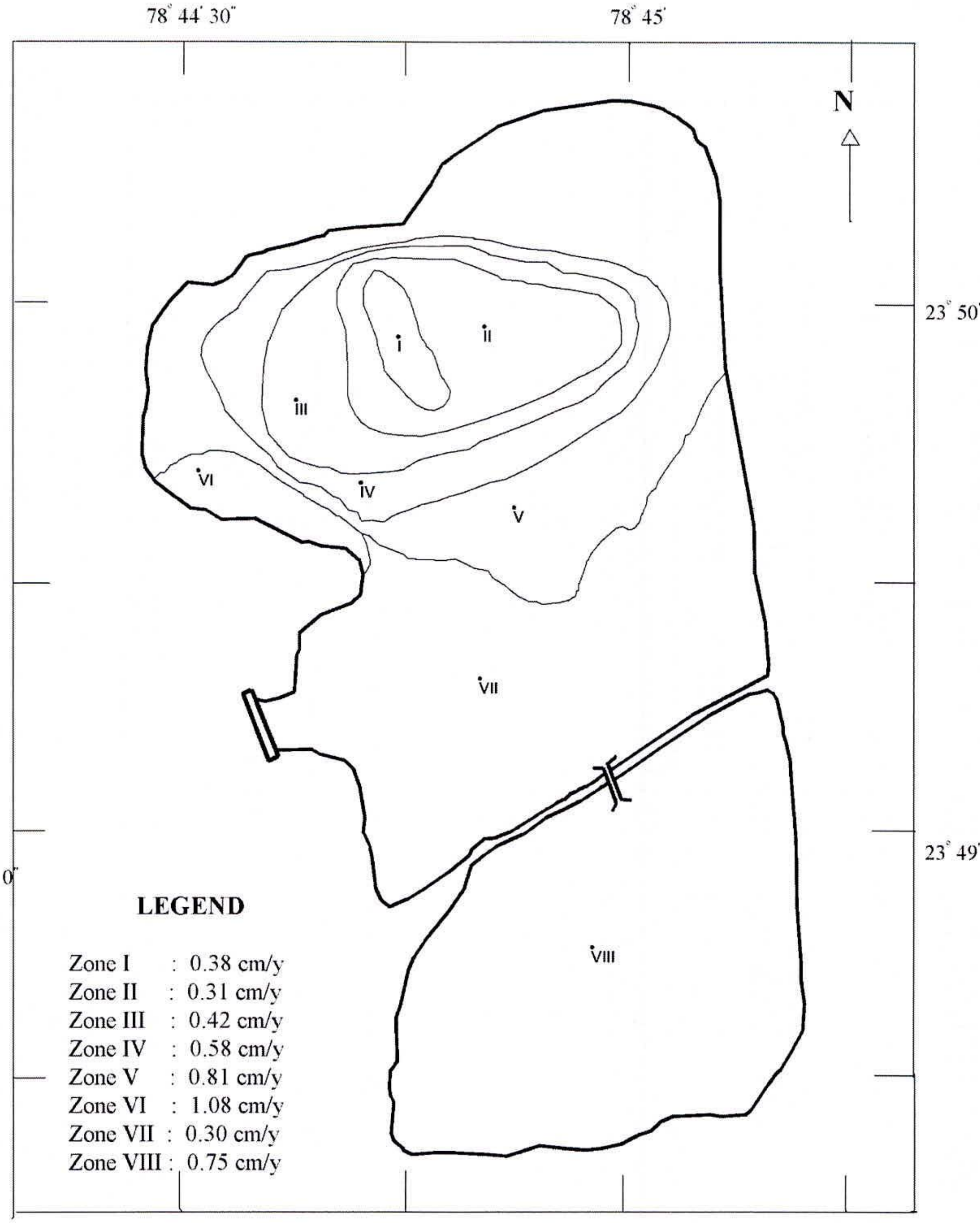


Fig. 21: Sedimentation rate in the eight zones of Sagar lake

The useful life of the Sagar lake has been estimated by using the area-weighted mean rate of sedimentation and the mean depth of the lake. The estimated life of Sagar lake, considering an average rate of sedimentation since 1964, is about 467 years (Table 14).

7.0 CONCLUSIONS

Sedimentation rate in the lake is varying between 0.30 cm/y to 1.08 cm/y with the mean sedimentation rate 0.58 cm/y± 0.002 cm/y. The rates of sedimentation are higher in the Zone V, VI, VIII, moderate in the zone III and IV and lower in the zone I, II and VII (Fig. 21). Higher rate of sedimentation in Zone VIII (small lake) is mainly due to sediment inflow through the Kanera canal and nearby agricultural fields. Zone VI is receiving the highest rate of sediment due to erosion from upland area. Sediments entering in this area accumulate in a small pocket. Also, the developmental activities in the catchment area and erosion from foothills contribute a high rate of sedimentation in zone V. A lower rate of sedimentation in zone I and II (deeper portion) is because coarser particles gets settle down near the bank and only finer particles move towards the central portion of the lake.

The estimated useful lake life, based on Post-1964 mean rate of sedimentation of the lake i.e., 0.58±0.02 cm/y is about 467 years.

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Table 1: Sediment sample density and ^{137}Cs activity of core A

Depth (cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.10	38
3	0.18	32
5	0.28	38
7	0.26	42
9	0.32	39
11	0.34	26
13	0.40	36
15	0.40	38
17	0.41	45
19	0.37	23
21	0.38	37
23	0.34	42
25	0.47	31
27	0.45	30
29	0.39	23
31	0.44	67
33	0.42	296

Table 2: Sediment sample density and ^{137}Cs activity of core B

Depth (cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.22	30
3	0.23	48
5	0.29	28
7	0.26	33
9	0.24	20
11	0.28	47
13	0.26	19
15	0.28	32
17	0.26	23
19	0.32	34
21	0.38	43
23	0.34	25
25	0.34	40
27	0.40	47
29	0.39	68
31	0.27	48
33	0.39	33
35	0.47	13
37	0.44	77

Table 3: Sediment sample density and ^{137}Cs activity of core C

Depth (cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.15	66
3	0.37	51
5	0.28	39
7	0.37	43
9	0.36	29
11	0.35	38
13	0.36	11
15	0.36	41
17	0.30	15
19	0.23	11
21	0.31	42
23	0.44	43
25	0.46	47
27	0.53	35
29	0.44	67
31	0.62	35
33	0.69	26

Table 4: Sediment sample density and ^{137}Cs activity of core D

Depth (cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.32	33
3	0.33	44
5	0.46	28
7	0.67	16
9	0.68	21
11	0.66	43
13	0.79	20
15	0.72	11
17	0.75	23
19	0.82	26
21	0.80	22
23	1.00	19

Table 5: Sediment sample density and ^{137}Cs activity of core H

Depth (cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.10	37
3	0.26	26
5	0.25	31
7	0.28	37
9	0.30	19
11	0.41	33
13	0.34	28
15	0.37	30
17	0.37	43
19	0.31	34
21	0.34	25
23	0.29	32
25	0.31	25
27	0.36	37
29	0.39	35
31	0.38	20
33	0.53	24
35	0.63	28
37	0.51	24
39	0.55	168

Table 6: Sediment sample density and ^{137}Cs activity of core K

Depth (cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.19	92.1
3	0.19	114.15
5	0.19	138.29
7	0.20	113.33
9	0.20	92.57
11	0.21	76.75
13	0.28	53.04
15	0.23	48.12
17	0.25	50.62
19	0.21	60.68
21	0.29	42.65
23	0.23	38.05
25	0.24	38.53
27	0.23	51.64
29	0.21	38.72
31	0.25	39.71
33	0.27	34.45
35	0.23	40.23
37	0.22	38.64
39	0.21	71.27
41	0.21	33.42
43	0.30	27.34
45	0.25	30.68
47	0.24	39.79

Table 7: Sediment sample density and ^{137}Cs activity of core L

Depth(cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.08	30
3	0.09	69
5	0.08	28
7	0.13	23
9	0.10	28
11	0.11	106
13	0.12	23
15	0.11	12
17	0.13	16
19	0.13	7
21	0.15	16
23	0.15	8
25	0.15	11
27	0.19	8
29	0.20	19

Table 8: Sediment sample density and ^{137}Cs activity of core M

Depth (cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.14	12.16
3	0.20	42.27
5	0.21	33.54
7	0.20	47.49
9	0.22	33.47
11	0.19	56.75
13	0.16	76.16
15	0.18	32.25
17	0.21	41.37
19	0.22	54.33
21	0.17	122.78
23	0.20	112.12
25	0.17	98.37
27	0.25	64.72
29	0.18	101.45
31	0.19	95.9
33	0.22	55.4
35	0.21	43.02
37	0.39	37.18
39	0.31	28.43
41	0.24	39.32
43	0.30	40.74
45	0.18	36.97
47	0.16	73.02

Table 9: Sediment sample density and ^{137}Cs activity of core N

Depth(cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.10	18
3	0.12	12
5	0.19	29
7	0.18	19
9	0.27	21
11	0.44	14
13	0.44	7
15	0.50	9
17	0.43	32
19	0.16	31
21	0.41	0
23	0.38	27
25	0.43	89
27	0.46	46
29	0.46	147
31	0.32	36

Table 10: Sediment sample density and ^{137}Cs activity of core O

Depth(cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.22	24
3	0.17	88
5	0.17	29
7	0.23	45
9	0.19	41
11	0.23	43
13	0.21	38
15	0.18	116
17	0.22	42
19	0.25	30
21	0.25	64
23	0.23	49
25	0.23	94
27	0.18	41
29	0.23	8
31	0.23	20
33	0.21	51
35	0.19	58
37	0.19	65
39	0.17	6
41	0.29	60
43	0.19	12
45	0.24	48
47	0.20	64
49	0.22	57

Table 11: Sediment sample density and ^{137}Cs activity of core Q

Depth(cm)	Density (g/cc)	^{137}Cs (mBq/g)
1	0.08	25
3	0.12	35
5	0.09	24
7	0.16	30
9	0.21	34
11	0.38	38
13	0.88	36
15	0.68	32
17	0.82	40
19	0.65	53
21	0.77	64
23	1.01	196
25	1.25	136
27	1.34	324

Table 12: Rate of sedimentation in Sagar lake determined using radiodating techniques

Sediment Core	Sedimentation rate (cm/y) using ^{137}Cs dating	Sedimentation rate (cm/y) using ^{210}Pb dating
Core A	0.92 ± 0.029	ND*
Core B	0.81 ± 0.029	0.71
Core C	0.81 ± 0.029	1.03
Core D	0.31 ± 0.029	ND*
Core E	ND*	0.30
Core H	1.08 ± 0.029	ND*
Core K	0.38 ± 0.029	0.47
Core L	0.31 ± 0.029	ND*
Core M	0.58 ± 0.029	ND*
Core N	0.81 ± 0.029	0.97
Core O	0.42 ± 0.029	ND*
Core P	ND*	ND*
Core Q	0.75 ± 0.029	ND*

ND*: Not Determined

Table 13: Comparison of sedimentation rate of different lakes with Sagar Lake

Lake	Lake Basin Area (km^2)	Sedimentation rate (cm/y)	Dating Techniques	Workers
Nainital	4.7	0.64 to 1.24 (M.P.)	^{210}Pb	Bhishm Kumar et al., 1999
		1.15 (S.P.)	^{210}Pb	Das et al., 1994
		0.60 to 1.35 (M.P.)	^{137}Cs	Bhishm Kumar et al., 1999
Bhimtal	11.72	0.68 (S.P.)	Radiocarbon	Kusumgar et al.,1989
		0.47 (S.P.)	^{210}Pb	Das et al., 1994
Naukuchiatal	3.23	0.37 (S.P.)	^{210}Pb	Das et al., 1994
Sattal	4.32	0.39 (S.P.)	^{210}Pb	Das et al., 1994
Mansar	1.67	0.14 to 0.37 (M.P.)	^{137}Cs	Bhishm Kumar et al., 2000
		0.20 to 0.34 (M.P.)	^{210}Pb	
Sagar	1.45	0.31 to 1.08 (M.P.)	^{137}Cs	Present Study
		0.30 to 1.03 (M.P.)	^{210}Pb	

Table 14: Estimation of lake life using radiometric dating of sediments

Technique used	Lake zone	Area (m^2)	Sedimentation rate (cm/y)	Sediment accumulation rate (m^3/y)	Estimated lake life (y)
^{137}Cs	I	22880	0.38 ± 0.029	87 ± 07	467
	II	109280	0.31 ± 0.029	339 ± 32	
	III	79360	0.42 ± 0.029	333 ± 23	
	IV	107520	0.58 ± 0.029	624 ± 31	
	V	318080	0.81 ± 0.029	2576 ± 92	
	VI	36000	1.08 ± 0.029	389 ± 10	
	VII	402720	0.30 ± 0.029	1208 ± 117	
	VIII	372160	0.75 ± 0.029	2791 ± 108	