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SEDIMENTATION STUDY OF MANSAR LAKE, DISTRICT UDHAMPUR (J&K)

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PREFACE

In recent years the impact of human activities on lakes have been acutely felt throughout the entire Himalayas. The major problems being noticed from the Himalayan lakes are deterioration in water quality and increasing sedimentation rate. Sedimentation in the lake reduces storage capacity, light penetration, encourages biotic growth and affects the functioning of lake ecosystem. In the Siwalik terrain of Jammu region, two lakes, namely Mansar and Surinsar are located. Mansar lake has been developed as tourist spot in the Jammu region. This lake is also being used for drinking and irrigation purposes. It is famous also for its religious importance. Mansar lake receives sediment from the lower Siwalik formation, which is highly prone to erosion due to geological and tectonic set-up. Deforestation, construction activities to develop tourism in the lake catchment and inflow from agricultural land areas have accelerated the sedimentation rate in the lake. Local authorities are worried that the Mansar lake is being filled up by sediment at a faster rate and lake volume is reducing rapidly.

Keeping in view the above concern, Regional Coordination Committee of the Western Himalayan Regional Centre of the Institute recommended carrying out the sedimentation study of Mansar lake. For the first time, sedimentation rate and its pattern in the lake has been investigated using radiometric dating technique. Life of lake based on post-1964 average sedimentation rate has been predicted. The result of this study will be helpful in preparing the strategies for environmental management of the lake.

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ABSTRACT

Mansar lake is situated about 55 km East of Jammu City at an elevation of 666 metres above mean sea level in the Siwalik terrain of Jammu region. Lake surface area is 0.59 km^2 and lake basin area is 1.67 km^2. The maximum depth of lake is 38.25 meter. It has been developed as tourist spot in the Jammu region due to its natural beauty. The lake water is also being used for drinking and irrigation purposes. The lake catchment is composed of lower Siwalik rocks, which are highly prone to erosion. It has been felt that Mansar lake is shrinking very fastly due to high rate of siltation.

In recent years radiometric dating techniques (i.e., ^{137}Cs and ^{210}Pb) have been proved as reliable tools for estimation of sedimentation rate. Study of rate of sedimentation and pattern in Mansar lake has been carried out using ^{137}Cs and ^{210}Pb radiometric dating techniques. Five sediment cores at different location from Mansar lake were collected in order to determine the rate of sedimentation. Rate of sedimentation obtained using ^{137}Cs varies between 0.14 to 0.37 cm/y depending upon the location in the lake. Sedimentation rates have also been estimated at three locations using ^{210}Pb dating technique. These vary from 0.24 cm/y to 0.34 cm/y that are comparable with the rates estimated using ^{137}Cs dating technique. The mean rate of sedimentation in lake using ^{137}Cs results is 0.23±0.031 cm/y. Results obtained by ^{137}Cs technique are used to compute the life of Mansar lake. The predicted life based on Post-1964 mean rate of sedimentation of Mansar lake (0.23 ± 0.02 cm/y) is about 9110 ± 790 years.

1.0 INTRODUCTION

Life span of Himalayan reservoirs and lakes has been drastically reduced as a result of higher rate of sedimentation. The faster rate of sedimentation in reservoirs means quickened pace of erosion in the catchment areas. The planners of the dams had estimated the rate of sediment-yield of the Himalayan rivers, according to Singhal et al., (1979), at 6.14 hectare-metre per 100 km^2 y^{-1}. It has now been found to be about 16.43 hectare-metre per 100 km^2 y^{-1}. Similarly, eroded material is carried into the lake by streams, river as well as overland flow entering into the lake. Several Himalayan lakes such as Dal lake of Jammu and Kashmir, Nanital and Bhimtal lake of Uttranchal are shrinking due to heavy input of eroded material. Delivery of sediment depends upon slope, vegetation cover and geology of the lake catchment. Sediment entered into the lake deposits slowly on the lake floor as natural processes of sedimentation. Sedimentation in the lake reduces its storage capacity, light penetration and encourage biotic growth and affects the functioning of lake ecosystem (Bhargava and Mariam, 1991). 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.

In recent years, the impact of human activities on lakes has been acutely felt throughout the entire Himalaya. Deforestation and accelerated erosion rate in the Lesser Himalaya at the rate of 170.3 cm/1000y have greatly affected the hydrological regime in the past 50 years (Valdiya and Bartarya, 1989). It has been felt that the lakes are reducing fastly due to high siltation rate. Study of sedimentation in lakes is highly complex process. In this connection, rates of sedimentation using dating techniques have been estimated for various lakes situated in the Uttaranchal (Kusumgar et al., 1989; Das et al., 1994; and Bhishm Kumar et al., 1999). Sedimentation rate in lake Nainital varies between 0.60 cm/y to 1.15 cm/y (Bhishm Kumar et al., 1999).

In Siwalik Himalaya of Jammu region, there are two prominent lakes, namely Mansar and Surinsar, located in the east of the Jammu city. Mansar has been developed as tourist spot in the Jammu region due to its natural beauty. The lake water is also being used for drinking and irrigation purposes. It has been felt that the Mansar 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, an attempt has been made to study rate of sedimentation of Mansar lake using radiometric dating techniques i.e., ^{137}Cs and ^{210}Pb, and life of the lake has also been determined.

2.0 STUDY AREA

Mansar lake is situated about 55 km East of Jammu City, between longitude 75^0 5' 11.5" to 75^0 5' 12.5" E and latitude 32^0 40' 58.25" to 32^0 40' 59.25" N, at an elevation of 666 metres above mean sea level in the Siwalik Himalaya. There is no channelised surface inflow into the lake (Fig. 1). The lake receives fresh water from the precipitation over the lake basin area, which flows into the lake as overland flow. During the rainy season, when water level rises in the lake, overflow from the lake takes place through man made outlets (i.e., pipes) draining into the Mansar Wali Khad, which later joins Ghambir Khad. Lake water level varies between 1.5 to 2 m in a year, it reaches maximum in September/October and minimum in May/June. Western flank of the lake basin is covered by the agricultural fields, school and Sesnag temple, Northern flank by Mansar Bazaar, Block Offices and forest rest house etc, Eastern flank by tourism guest house, tourism office, shops etc, and Southern flank by wild life sanctuary, Samshan Ghat, and the hill slope is covered by forest.

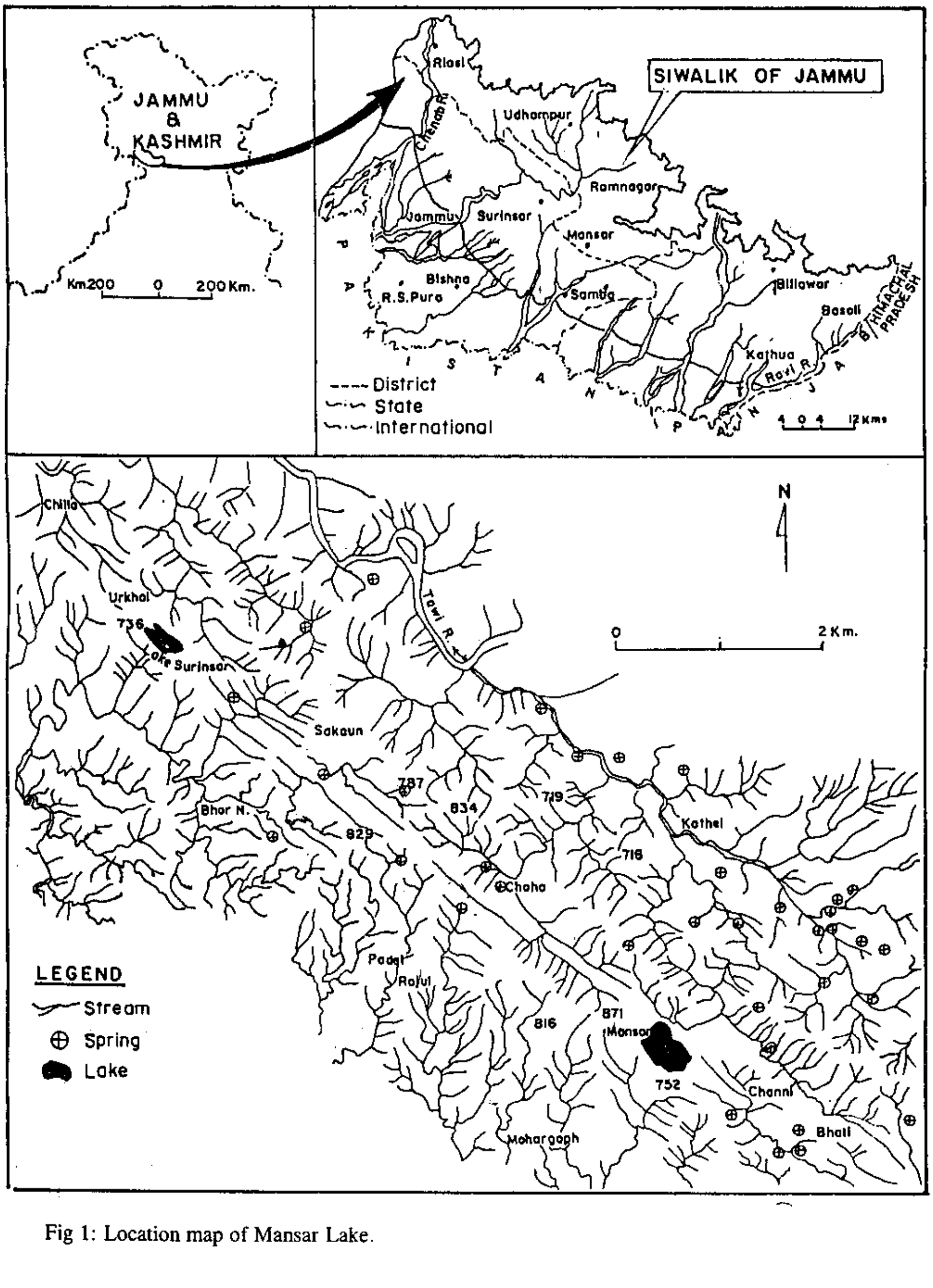


Fig 1: Location map of Mansar Lake.

Climatically, the area falls under the subtropical region. Monsoon rains are received from July to September and the winter rains during January to March. The average annual rainfall is 150 cm. Air temperature varies between 3^0 C (minimum) in winter to 43^0 C (maximum) during peak summer. Lake water temperature at surface varies between 14^0 C (minimum) in January to 31^0 C (maximum) in July.

The reserve forest on the western bank of the catchment covers 0.11 km^2 and is mainly represented by *Mangifera indica*, *Ficus religiosa*, *Pinus roxburghii* and other subtropical type plants. Mansar is heavily infested with macrophytes, weeds and submerged biota. Various species of submerged macrophytes such as *C. demersum*, *H. verticillata*, *V. spiralis and P. crispus*, *N. indica*, *P. lucens* and *P. salicifolicus* are reported from Mansar lake (Sharma, 1994). Algae belonging to different classes i.e., *Cyanophyceae*, *Chlorophyceae* and *Bacillariophyceae* have been reported from these lakes. Chander Mohan (1993) reported that macrophytic biomass increase in summer due to increase temperature and day length and biomass decrease in winter. Important fauna of the lake are fresh water medusa, large swimming insects, fishes, frogs and turtles etc. Gupta (1992) have reported five species of fishes in the Mansar lake. These are *Puntius conchonius*, *Rasbora rasbora*, *Danio rario*, *Channa gachua and Trichogaster*.

2.1 Geology of the Area

Medlicott (1876) first studied the geology of the Siwalik belt in Jammu Region. Among various other workers, Wadia (1928), Hazra (1938), Bhatt (1963) and Karuna Karan and Ranga Rao (1976) have studied in detail the stratigraphy and depositional environment of Siwalik belt of Jammu. Gupta and Verma (1988) have studied the geology of the Siwalik rocks near the study area.

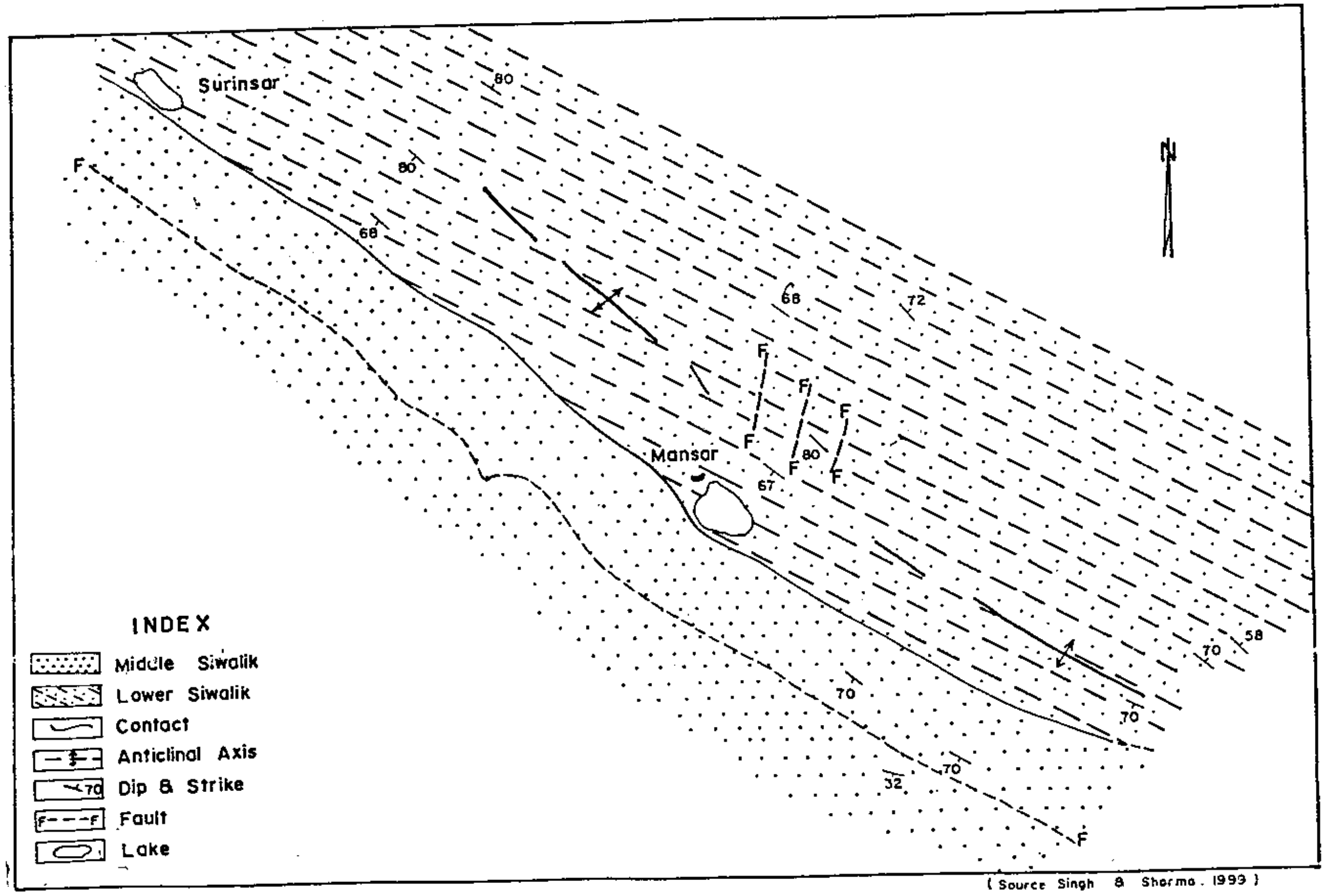
The Mansar lake is situated in the Lower Siwalik rocks composed of sandstone alternating with clay bands of 1-2 m thickness. It consists of alternating layers of fine grained, hard and compact sandstone, silt stone, mudstone and clay. The sandstone are buff, grey and light greenish grey in colour. The clays are purple, brown, red and yellowish red (Gupta and Verma, 1988).

WNW-NW to ESE-SE trending anticlinorium, namely Surin-Mastgarh anticline is passing through the study area (Fig. 2). The Surinsar- Mastgarh anticlinorium, is a subhorizontal, upright fold plunging 5^0 towards $S52^0E$. The NNE-SSW trending faults have displaced the anticlinorium axes at several places (Singh and Sharma, 1999). Occurrence of Mansar and Surinsar lakes along strike direction of anticline axes indicate that lakes are interconnected with each other.

2.2 Morphometric Characteristics

A bathemetric survey of the Mansar lake was carried by Rai et al (1998-99). In this study, it was found that lake surface area is 0.59 km^2 and the lake basin area is 1.67 km^2. The maximum depth is 38.25 meter. The maximum length and width of the lake is 1204 metres and 645 metres, respectively. The lake mean width is 490 metres and mean depth is 20.97 m. Circumference of the lake is 3.4 km. The ratio of mean depth and maximum depth is 0.55. A higher value of this ratio reveals that the lake basin is U shaped with steep sides and flat bottom. Development of the volume of lake is 1.64, indicating that basin walls are essentially concave towards the water.

Slope of the lake between 0.0 - 5.75 m depth is 0.21 m/m, covers 12.7% area of the total lake. The slope is maximum (0.30 m/m) between 5.75 - 10.75 m depth contour interval and minimum (0.04 m/m) between 35.75 to 38.25 m depth. The mean slope of the lake basin is 0.14 m/m. About 17% of the area of the total lake is with 0.08 m/m slope between 25.75 - 30.75 m depth interval.



(Source Singh & Sharma . 1999)

Fig. 2: Geological setup around the Mansar lake

Maximum capacity of lake is computed to be 12.37 Mm^3 of which maximum 25.85% is between 0-5.75 m depth, 19.76% between 5.75-10.75 m and 17.41% between 10.75-15.75 m depth. Thus, 63 % of the total lake volume is up to 15.75 m depth and remaining 37% below the 15 m.

2.3 Origin of the Lake

There are several myths about the origin of Mansar lake, but a common geological belief is that the lake owes its origin due to the damming of the river which was flowing along the strike of the Lower Siwalik range (Zutshi, 1985). The peaty and sticky soil surrounding almost the entire area of the lake, which might have been of greater dimensions in the past, support these observations. Krishnan and Prasad (1970) have reported that the Mansar and Surinsar lakes are ten to fifteen thousand years old.

Trellis and parallel type drainage pattern (Fig. 1) around the lake basin are evidence of the structural control on the drainage pattern. Sharp turns and straight reaches of streams are controlled by joints/fracture and faults which are developed due to tectonic activities of Himalaya. There is more possibility that origin of Mansar lake is due to the neotectonic movements in the Siwalik terrain.

3.0 BRIEF SUMMARY OF PREVIOUS WORK

In the last two decades, Himalayan lakes have drawn attention of many ecologists. Several studies have been conducted on the morphological and ecological aspects of Jammu and Kashmir lakes by investigators.

Physico-chemical and biological characteristics of Mansar lake have been studied by Zutshi, (1985, 1989), Zutshi et al., (1980), Chander Mohan, (1992) and Gupta, (1992). Using radioactive Carbon Isotope (^{14}C), production rates of Surinsar lake is much higher than that of the Mansar lake. On the basis of production rates, Surinsar lake has been categorised as eutrophic and Mansar as mesotrophic (Khan and Zutshi, 1979). Omkar and Sharma (1994-1995) carried out the water quality study of the Surinsar lake. Rai, et al.(1996-97 and 1997-98) studied the physico-chemical characteristics of Mansar lake and horizontal and vertical variations of various physico-chemical parameters in lake water. These studies reveal that Mansar lake has entered into eutrophic stage.

Various workers have made attempt to understand the ecological aspects of Mansar lake but no attention has been paid to the study of sedimentation in Jammu region lakes. Sedimentation study of various lakes of Uttaranchal such as Nainital, Bhimtal, Naukchiyatal and Sattal has been carried out 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 as 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 in lake/reservoirs. Various methods to determine the sedimentation rate in lakes are discussed in brief in following sections. The ^{210}Pb and ^{137}Cs dating techniques have been described in detail, which has been 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 utilizing 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 to bottom (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 of the method involve 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 utilized 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.

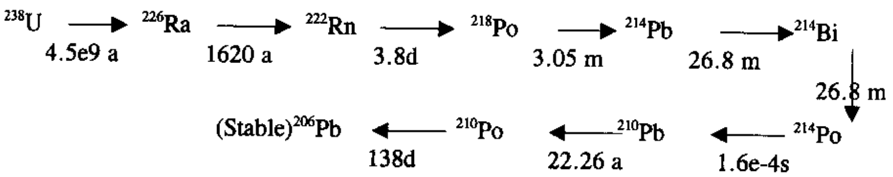
4.5 Radiometric Dating Techniques

Several environmental isotopes including ^{210}Pb, ^{137}Cs 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.



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 β - counting or through the α - counting of its grand-daughter, namely ^{210}Po, which is assumed to be in secular equilibrium with its parent. Direct β-counting of ^{210}Pb 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 α-counting of the grand-daughter product (^{210}Po) is more widely used. In this case, the basic radiochemical procedure involves adding of ^{208}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 sediments 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 (Bonyman et al., 1972; Balkamens 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 1986-87 due to Lopnor atomic test and Chernobyl accident.

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.

Practicalities 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; 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 International Atomic Energy Agency IAEA 300 Baltic sea sediment is available as a standard. It has a recommeded specific intensity of 1066.6 Bq/kg as on 1991.

5.0 METHODOLOGY USED FOR MANSAR 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 Paddle boat (Plate I). Inner and outer diameter of the corer is 5 cm and 6 cm, respectively. Sampling locations were selected on the basis of bathymetric map and sediment entry points in the lake. Five sediment cores were collected during May, 1999 from different locations (Plate II) and efforts were made to cover the maximum possible sedimentary environment. The length of the cores obtained ranged from 18 to 60 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 and ^{210}Pb activities. 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 550^0 C for 30 minutes.

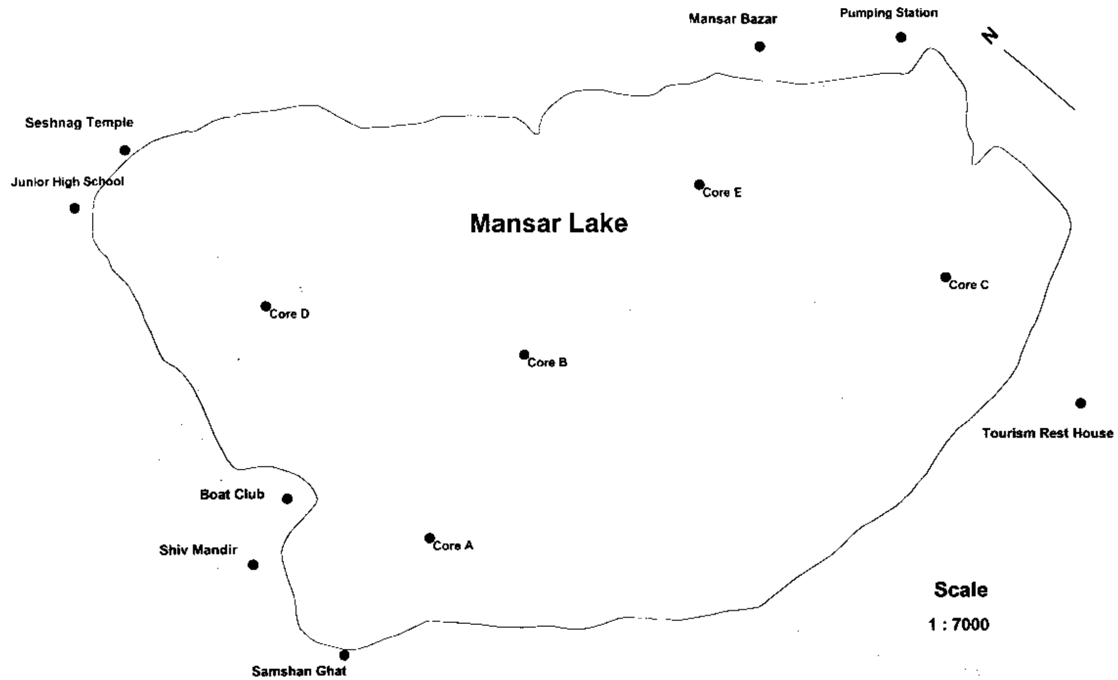
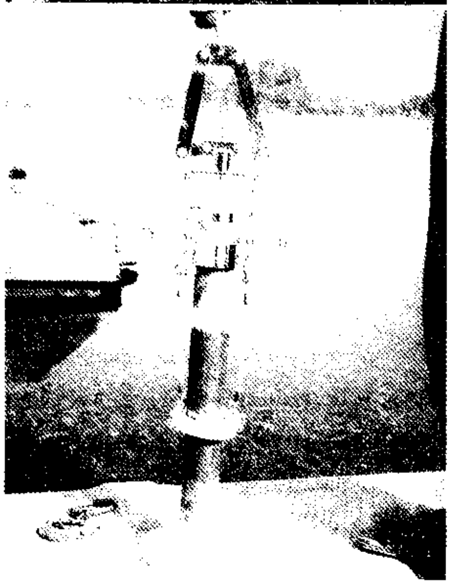


Fig. 3: Map showing sites of sediment core collected from the Mansar Lake

a



b

Plate IIa: View of gravity corer before sediment collection

IIb: View of gravity corer with collected sediment core

5.2 Dating of Sediment Cores

All the sliced core samples of five 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 HyperPure Germanium detector coupled with a 4096 channel multi-channel analyser system. A ^{137}Cs standard (IAEA-300), having essentially the same geometry and density was used. About 10 gm or less (if the wt. of sediment core was less than 10 gram) weight of the sliced cores were counted for about 7200 to 28800 sec 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 α-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 (Po-210) 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 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), 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, 110 samples of five cores were analysed using ^{137}Cs techniques. The activity of ^{137}Cs determined in all the five cores are presented in the Figures 4 to 8 along with organic matter and density. The sediment cores collected from different locations in Mansar lake contain organic matter in the range of 6 to 19%. Organic matter varies between 7 to 14% in core A, 10 to 19% in core B, 6 to 14 in core C, 9 to 16 % in core D and 8 to 16% in core E. The maximum amount of organic matter is found in the core collected from central portion of the lake at location B (Fig. 3). The higher percentage of organic matter lies in upper part of all the sediment cores, except core A. Loss on ignition shows decreasing trend with depth, dry density increases with depth and decreases with loss on ignition (Fig. 4,5,6,7 and 8) except in core A. Core A shows nearly same loss on ignition and dry density with depth which may be due to comparatively higher rate of sedimentation at location of core A since long time. The details of loss on ignition (organic matter) and dry density are given in (Tables 1 to 5).

Rate of sedimentation determined using ^{137}Cs techniques of the cores collected near the Boat Club area (core A), and in the vicinity of Mansar Bazar (core E) are about 0.37 cm/y (Table 6). The deeper portion area (>30 m depth) receives the sediment at a lower rate (i.e.,

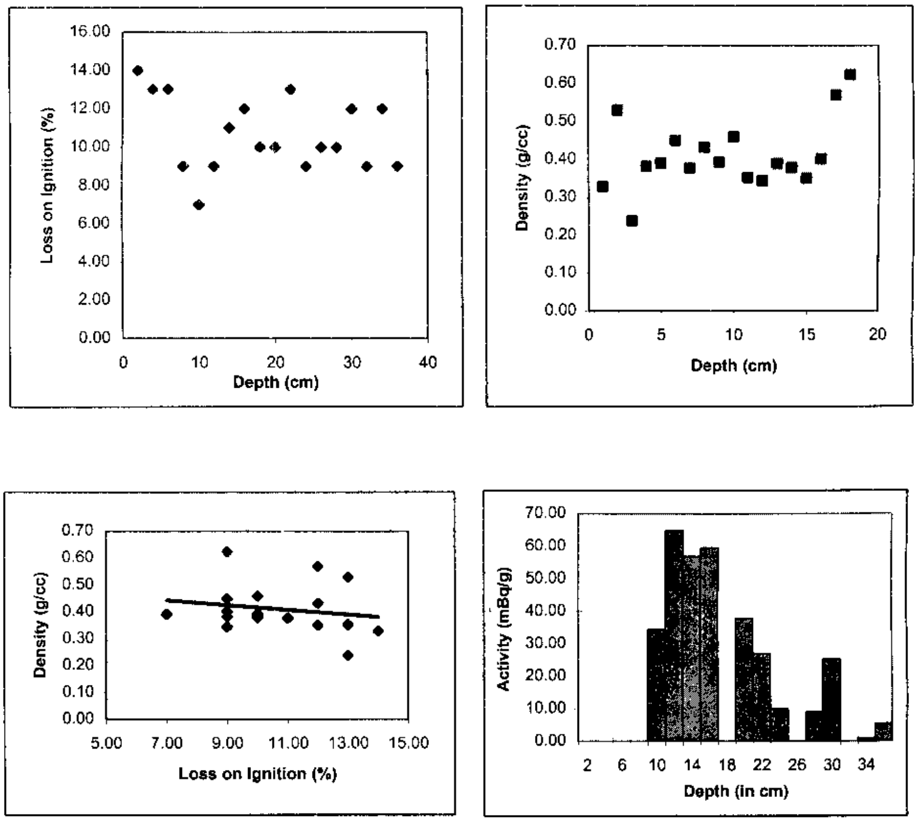


Fig. 4: Soil characteristics and dating details of Core A.

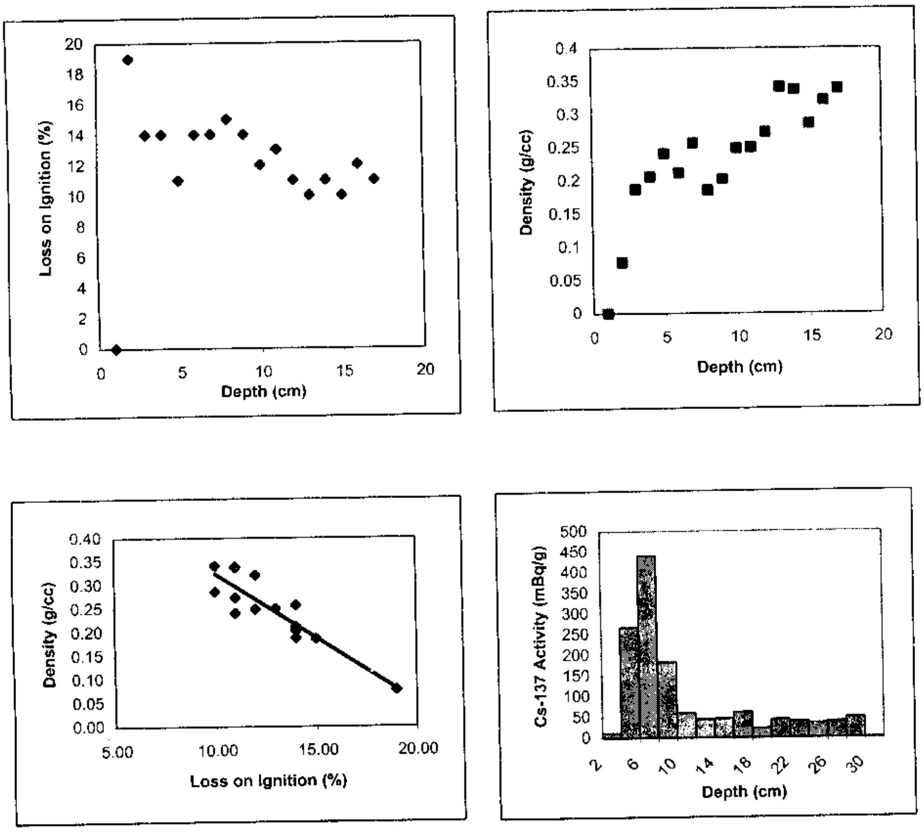


Fig. 5: Soil characteristics and dating details of Core B.

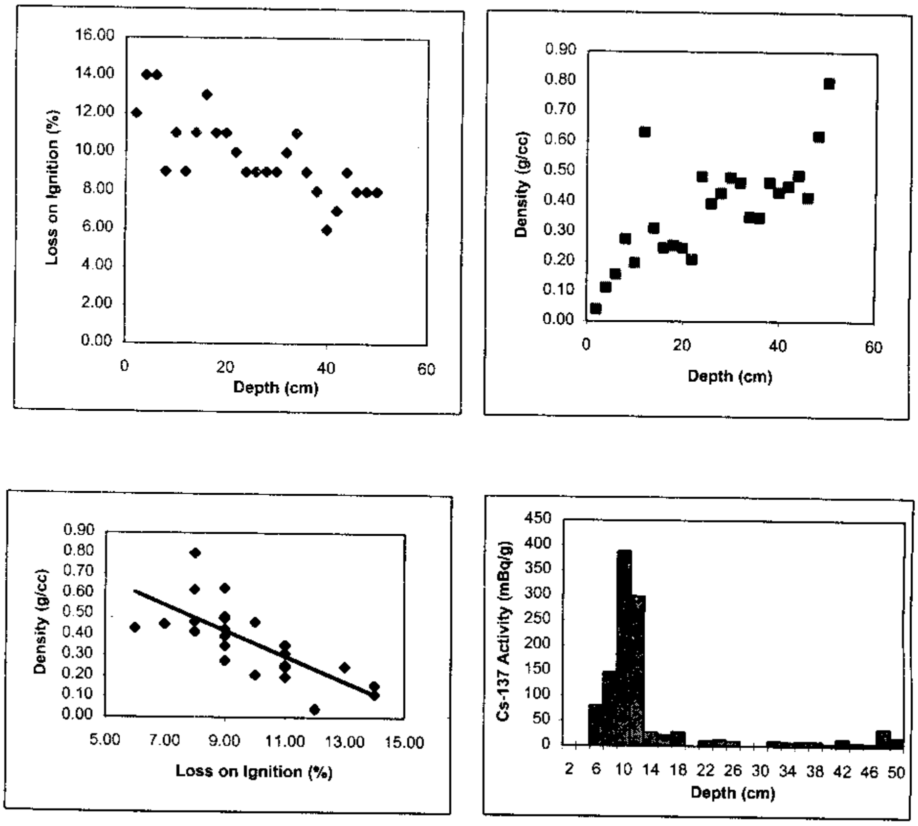


Fig. 6: Soil characteristics and dating details of Core C

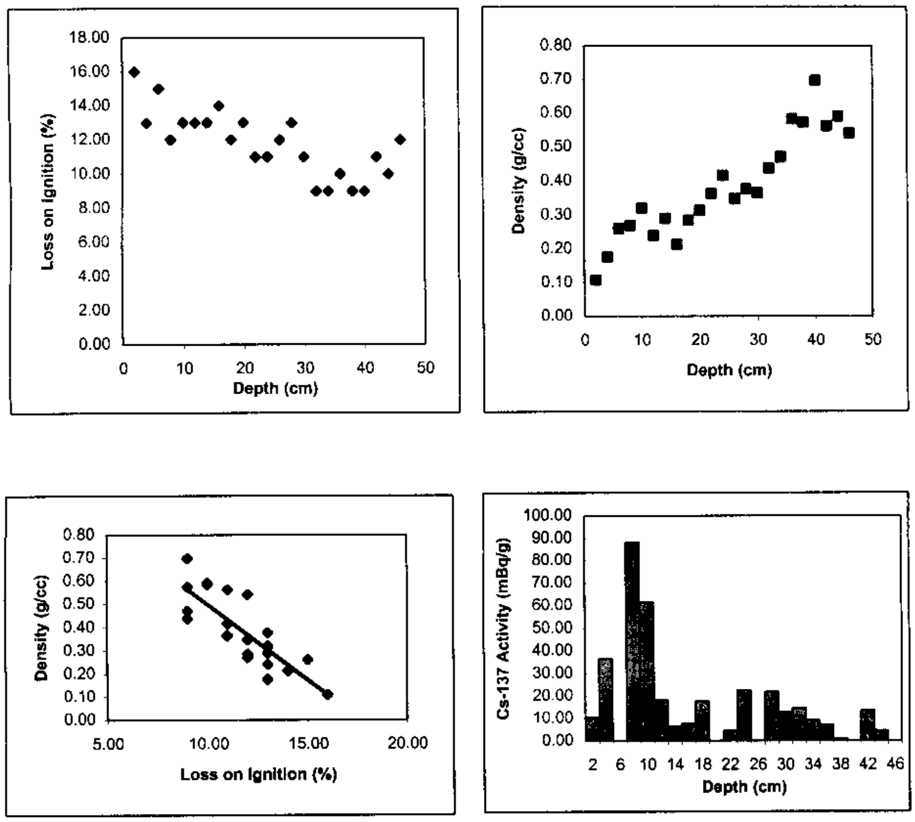


Fig. 7: Soil characteristics and dating details of Core D

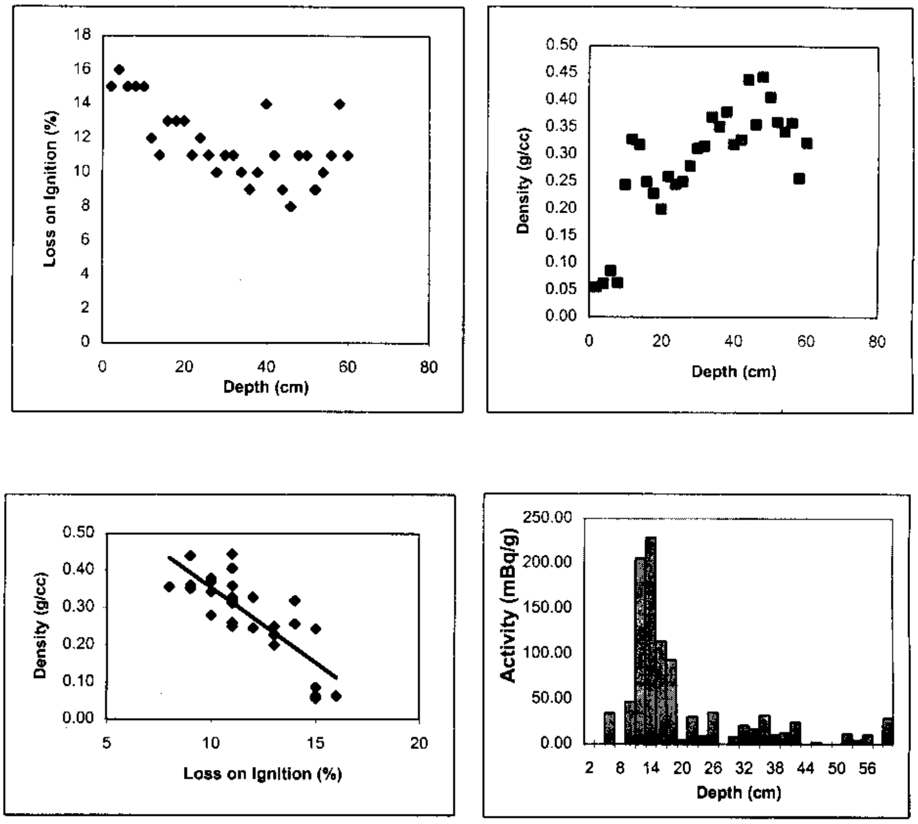


Fig. 8: Soil characteristics and dating details of Core E.

Table 1: Data pertaining to Core A collected atMansar.

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
2	14.00	0.33	0
4	13.00	0.53	0
6	13.00	0.24	0
8	9.00	0.38	0
10	7.00	0.39	34.27
12	9.00	0.45	64.94
14	11.00	0.38	56.82
16	12.00	0.43	59.52
18	10.00	0.39	0
20	10.00	0.46	37.88
22	13.00	0.35	27.06
24	9.00	0.34	9.92
26	10.00	0.39	0
28	10.00	0.38	9.02
30	12.00	0.35	25.25
32	9.00	0.40	0
34	12.00	0.57	0.9
36	9.00	0.62	5.41

Table 2: Data pertaining to Core B collected at Mansar.

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
2	19.00	0.08	0
4	14.00	0.19	305.22
6	14.00	0.21	472.25
8	11.00	0.24	204.79
10	14.00	0.21	98.64
12	14.00	0.26	54.78
14	15.00	0.19	97.39
16	14.00	0.20	78.42
18	12.00	0.25	34.4
20	13.00	0.25	81.23
22	11.00	0.27	59.95
24	10.00	0.34	57.72
26	11.00	0.34	65.94
28	10.00	0.29	68.65
30	12.00	0.32	27.96
32	11.00	0.34	0

Table 3: Data pertaining to Core C collected at Mansar.

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
2	12.00	0.04	0
4	14.00	0.11	0
6	14.00	0.16	80.42
8	9.00	0.28	147.01
10	11.00	0.20	388.5
12	9.00	0.63	297.84
14	11.00	0.31	27.96
16	13.00	0.25	22.87
18	11.00	0.25	28.86
20	11.00	0.25	0
22	10.00	0.21	10.91
24	9.00	0.48	13.53
26	9.00	0.40	10.82
28	9.00	0.43	0
30	9.00	0.48	0
32	10.00	0.46	10.82
34	11.00	0.35	8.12
36	9.00	0.35	10.15
38	8.00	0.47	9.02
40	6.00	0.43	5.41
42	7.00	0.45	14.43
44	9.00	0.49	7.22
46	8.00	0.42	5.41
48	8.00	0.62	35.17
50	8.00	0.80	18.04

Table 4: Data pertaining to Core D collected at Mansar.

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
2	16.00	0.11	10.41
4	13.00	0.18	36.54
6	15.00	0.26	0
8	12.00	0.27	88.23
10	13.00	0.32	61.33
12	13.00	0.24	18.19
14	13.00	0.29	6.33
16	14.00	0.21	7.91
18	12.00	0.28	17.59
20	13.00	0.31	0
22	11.00	0.36	4.51
24	11.00	0.42	22.55
26	12.00	0.35	0
28	13.00	0.38	21.65
30	11.00	0.36	12.63
32	9.00	0.44	14.43
34	9.00	0.47	9.02
36	10.00	0.58	7.22
38	9.00	0.57	0.9
40	9.00	0.70	0
42	11.00	0.56	13.53
44	10.00	0.59	4.51
46	12.00	0.54	0

Table 5: Data pertaining to Core E collected at Mansar.

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
2	15	0.06	0
4	16	0.06	0
6	15	0.09	34.69
8	15	0.06	0
10	15	0.24	47.27
12	12	0.33	205.63
14	11	0.32	229.08
16	13	0.25	114.54
18	13	0.23	93.23
20	13	0.20	4.48
22	11	0.26	30.57
24	12	0.25	9.4
26	11	0.25	35.32
28	10	0.28	0
30	11	0.31	8.28
32	11	0.32	20.74
34	10	0.37	17.14
36	9	0.35	32.47
38	10	0.38	10.82
40	14	0.32	12.63
42	11	0.33	24.35
44	9	0.44	0
46	8	0.36	1.8
48	11	0.44	0
50	11	0.41	0
52	9	0.36	11.72
54	10	0.34	4.51
56	11	0.36	10.82
58	14	0.26	0
60	11	0.32	28.86

0.14 cm/y in core B). Eastern part (in front Sesnag Temple, core D) and Western part (in front of Tourist Rest House, core E) of the lake are showing moderate rate of deposition (0.20 cm/y). The mean rate of sedimentation computed for the lake is 0.23 ± 0.02 cm/y.

Sedimentation rates have also been estimated at locations A, D and E using ^{210}Pb dating technique (Table 6, Fig. 9,10 and 11). These vary from 0.24 cm/y to 0.34 cm/y that are comparable with the rates estimated using ^{137}Cs dating technique.

Table 6: Sedimentation rate of Mansar lake determined using radiodating techniques

Sediment Core	Sedimentation Rate determined by ^{137}Cs	Sedimentation Rate determined by ^{210}Pb (using CFCS model)
Core A	0.37 ± 0.029	o.34±0.033
Core E	0.37 ± 0.029	0.31±0.027
Core D	0.20 ± 0.029	0.24±0.015
Core C	0.20 ± 0.029	ND*
Core B	0.14 ± 0.029	ND*

ND*: Not Determined

Sedimentation rate of Mansar lake has been compared with the other Lesser Himalayan lakes where radiometric dating techniques have been used for estimation of sedimentation rate (Table 7).

Kumaun Himalaya lakes lies between altitude of 1300 to 2000 m and receive annual rainfall about 2000 mm while Mansar lake is located at the altitude of 666 m where average annual rainfall is about 1500 mm. The catchment area of Nainital, Bhimtal, Naukuchiyatal and Sattal lakes are greater than that of Mansar lake (Table 7). Further, lake surface area of Mansar lake is 0.59 km^2 while surface area of Nainital, Bhimtal, Naukuchiyatal and Sattal lakes are 0.47 km^2, 0.46 km^2, 0.37 km^2, and 0.34 km^2, respectively. In addition, catchment of

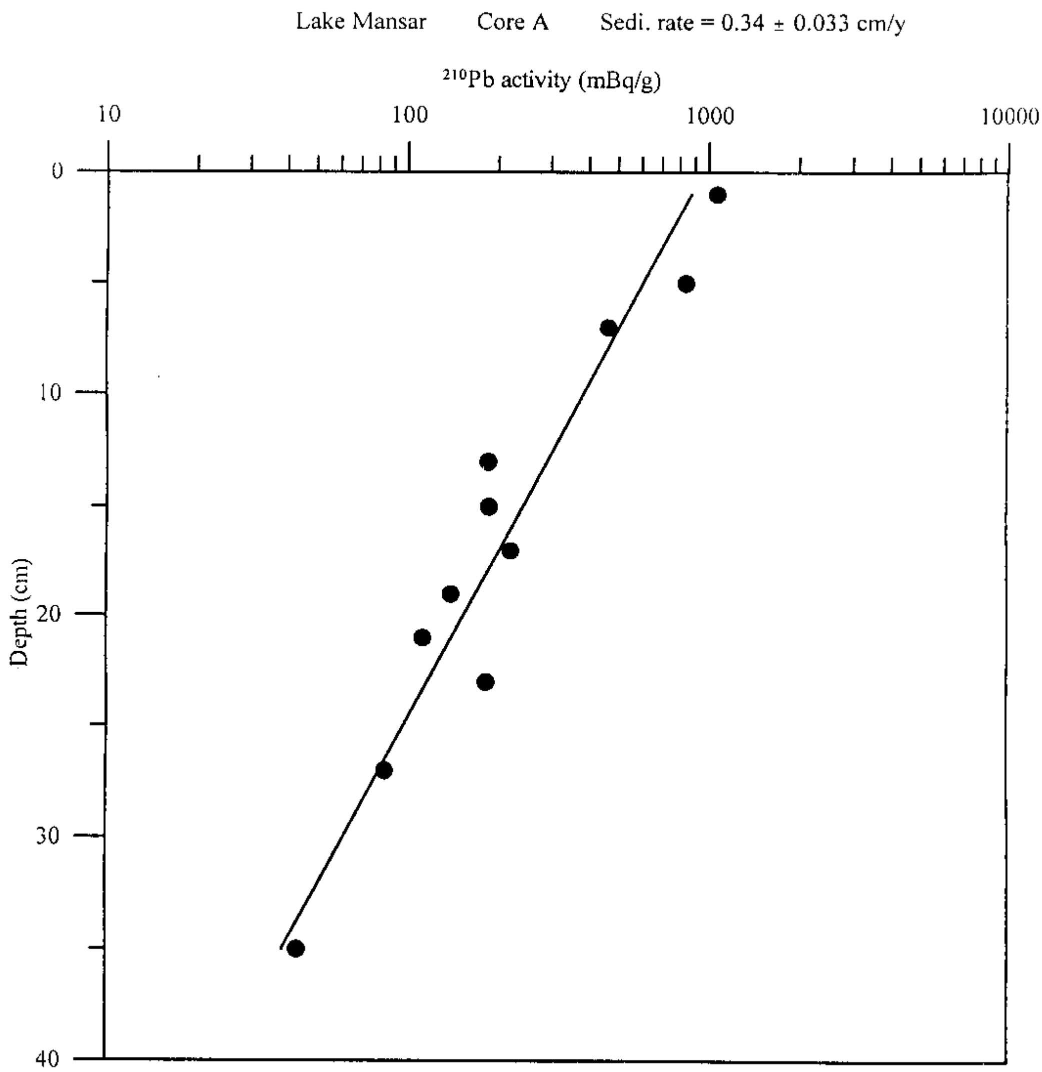


Figure 9: ^{210}Pb activity in sediment core A

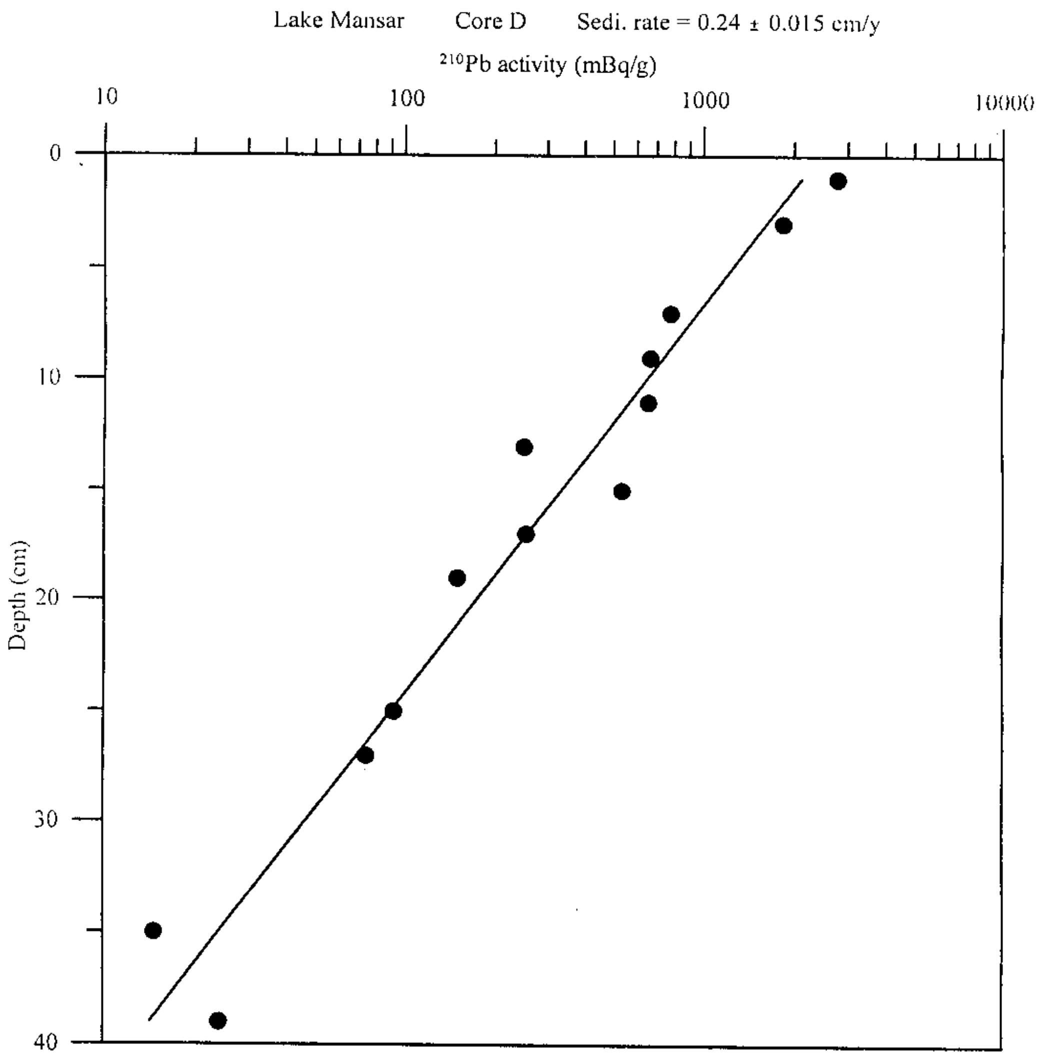


Figure 10: ^{210}Pb activity in sediment core D

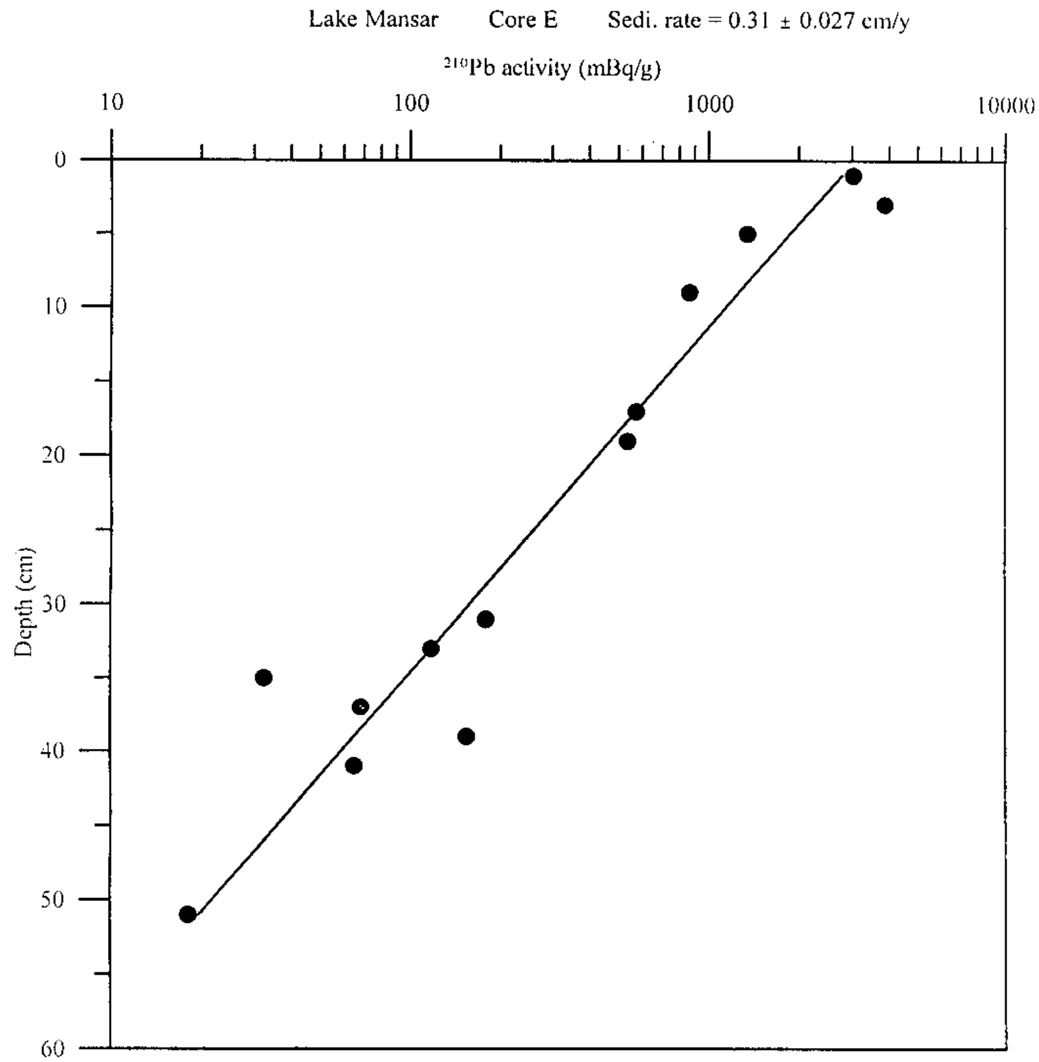


Figure 11 : ^{210}Pb activity in sediment core E

Nainital and Bhimtal lakes are comparatively more disturbed due to anthropogenic activities such as construction activities, agricultural practices etc. It is obvious that the settling basin area of Mansar lake is maximum and catchment area is smaller 2 to 2.5 times from Naukuvhiatal and Sattal lakes. However, equal rate of sedimentation and small catchment area of Mansar lake as compared to Naukuchiatal Sattal lake indicate that Mansar lake catchment area is getting eroded at higher rate.

Table 7: Comparison of sedimentation rate of Lesser Himalayan lakes with Mansar Lake

Lake	Lake Basin Area (km^2)	Sedimentation rate (cm/y)	Dating Techniques	Workers
Nainital	4.7	0.64 to 1.24	^{210}Pb	Bhishm Kumar et al., 1999
		1.15	^{210}Pb	Das et al., 1994
		0.60 to 1.35	^{137}Cs	Bhishm Kumar et al., 1999
Bhimtal	11.72	0.68	^{14}C	Kusumgar et al.,1989
		0.47	^{210}Pb	Das et al., 1994
Naukuchiatal	3.23	0.37	^{210}Pb	Das et al., 1994
Sattal	4.32	0.39	^{210}Pb	Das et al., 1994
Mansar	1.67	0.14 to 0.37	^{137}Cs	Present Study
		0.20 to 0.34	^{210}Pb	Present Study

6.1 Estimated Life of Mansar 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, Mansar lake has been divided into five zones (Fig. 12 and 13). The lake life

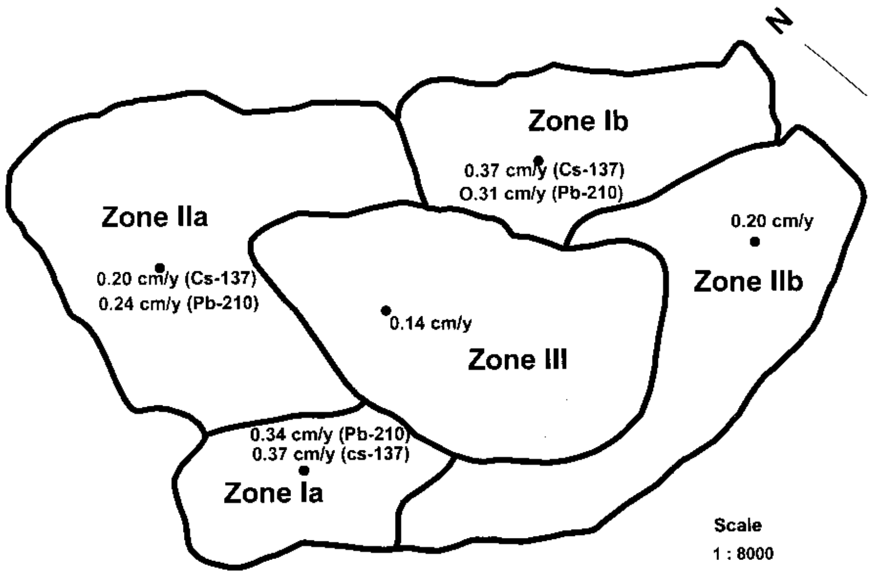


Fig. 13: Sedimentation rate in five zones of Mansar Lake

has been estimated taking into account the sediment accumulation rates obtained in all the five zones and the present volume of the lake as per the figures obtained on the basis of bathymetric survey of the lake carried out in 1999 (Rai et al., 1998-1999).

The useful life of the Mansar lake has been estimated by using the area-weighted mean rate of sedimentation and the mean depth of the lake. The estimated life of Mansar lake, considering an average rate of sedimentation since 1964, is about 9110 ± 790 years (Table 8).

Table 8: 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	Ia	59483	0.37 ± 0.029	220 ± 17	9110±790
	Ib	90633	0.37 ± 0.029	335 ± 26	
	IIa	165711	0.20 ± 0.029	331 ± 48	
	IIb	128701	0.20 ± 0.029	257 ± 37	
	III	145821	0.14 ± 0.029	204 ± 42	

7.0 CONCLUSIONS

The rate of sedimentation the lake varying between 0.14 cm/y to 0.37 cm/y and the mean rate of sedimentation is 0.23 cm/y ± 0.002 cm/y. The rates of sedimentation are higher in the Zone Ia, Ib, moderate in zone IIa and IIb, and minimum in zone III, which represent deeper portion of the lake (Fig. 13). Higher rate of sedimentation in Zone Ia is mainly due to erosion from agricultural land area. Zone Ib is receiving higher rate of sediment due to erosion from agricultural land and anthropogenic activities like development of market and road. Sediments entering in these areas accumulate in small pockets due to under water ridges. Zone IIa (Eastern part, in front of Sesnag Temple) showing moderate rate of deposition. A flat grass land area in the vicinity of zone IIb (Western part, in front of Tourist Rest House) acts as sediment barrier for the runoff entering into this zone from the agricultural and forested land. A lower rate of sedimentation in III zone (deeper portion) is because coarser particles gets settle down near the banks and only finer particles move towards the central portion of the lake. Smaller catchment area, larger lake surface area and comparatively lesser anthropogenic activities while rate of sedimentation comparable to Kumaun lakes suggest that Mansar lake catchment is more prone to erosion.

The estimated useful life of Mansar lake, based on Post-1964 mean rate of sedimentation of the lake (0.23 ± 0.02 cm/y) is about 9110 ± 790 years.

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