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ESTIMATION OF RATES AND PATTERN OF SEDIMENTATION AND USEFUL LIFE OF DAL - NAGIN LAKE IN J&K USING NATURAL FALLOUT OF Cs-137 & Pb-210 RADIOISOTOPES

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PREFACE

The Dal-Nagin lake is not only an attraction and means of recreation for the several thousands of tourists who visit Srinagar every year but, it is also the life-line for the several lakhs of people who have settled around it. In past few decades, the quantity and quality of lake water have deteriorated due to increasing anthropological activities in the lake catchment. For proper management of lake environment, it is necessary to consider the contribution of various factors that are responsible for the reduction in lake capacity, deterioration in water quality and overall degradation in the ecological environment of the lake. With the increase of scientific knowledge, and advancements in scientific techniques and instrumentation, it is now possible to investigate the various processes individually.

The Institute was given the task of estimation of the rates of sedimentation and useful life of Dal-Nagin lake using radiometric dating techniques of sediment under a project sponsored to Alternate Hydro Energy Centre, University of Roorkee, Roorkee by the Ministry of Environment and Forest, Government of India, in the month of Dec. 2000. The time available to complete this project was very limited (6 months) but, with continuous efforts and hard work put in by Dr. Bhishm Kumar, Sc. E and Mr. Rm. P. Nachiappan, Sc.B, of the Institute, this project has been completed with in the stipulated period.

Efforts have been made to bring out the maximum possible information about the rates and pattern of sedimentation in Dal-Nagin lake using environmental isotopes like ^{137}Cs and ^{210}Pb. The contribution of organic matters from external sources as well as those produced internally due to intense underwater weeding has been determined. It is important to note that the underwater weeds contribute about 25% in lake sedimentation process. The useful life of Dal lake has also been estimated which comes around 154 ± 12 years, if the average rate of sedimentation is taken since 1964 and 364 ± 50 years, if the average rate of recent sedimentation is taken since 1987. It clearly indicates the effect of settlement basin, which has come into existence after 1987. However, the effect of settlement basin is not seen in case of Nagin lake as its estimated useful life remains nearly same in cases of post-1964 (0.41 ± 0.05 cm/y) and post-1987 (0.34 ± 0.03 cm/y) average rates of sedimentation that correspond to estimated useful life of 315 ± 38 years and 379 ± 33 years respectively.

Dr. Bhishm Kumar, Sc. E and Mr. Rm. P. Nachiappan, Sc. B at National Institute of Hydrology, have prepared this report with the assistance of Messers. Ratnesh Kumar, Y.S.Rawat and Sanjay Chamola who were engaged under this project.

It is hoped that this report will provide useful information on the status of past and present rates of sedimentation in Dal-Nagin lake including the estimates of useful life of the lake for taking possible remedial measures by the authorities concerned and for further investigations by other interested researchers.

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ABSTRACT

The Dal- Nagin lake is a Himalayan lake which is located in the heart of Srinagar at an average altitude of 1583m. The lake comprises of four major sub-basins, viz., Hazratbal, Bod Dal, Gagribal & Nagin. In spite of various ecological problems associated with Dal- Nagin lake, it has pride to be the largest fresh water lake in India. In past few decades the growth of underwater weeds and increasing rate of sedimentation have diverted the attention of administration/authorities at various levels and researchers in the country. Keeping in view the considerable reduction in the capacity of lake and deterioration in lake-water quality, the Ministry of Environment and Forest, Government of India and J & K Lakes & Waterways Development Authority, Srinagar jointly sponsored a project to AHEC, University of Roorkee for undertaking various scientific studies in order to evaluate the present condition of lake. The study of rates of sedimentation and estimation of useful life of Dal- Nagin lake using radiometric dating techniques of sediments was sponsored to the National Institute of Hydrology, Roorkee by AHEC, UOR, Roorkee during December 1999.

About 355 sediment samples, from the 14 sediment cores collected from the lake, have been analysed for ^{137}Cs while about 150 samples have been subjected for various chemical treatments followed by radiometric dating of ^{210}Pb. The current rate of sedimentation after 1986-87 obtained by ^{137}Cs in Hazratbal sub-basin varies from 1.25 ± 0.12 to 0.08 ± 0.08 cm/y (average from 1.60 ± 0.13 to 0.40 ± 0.05 cm/y after 1963-64), in Nagin sub-basin from 0.91 ± 0.11 to 0.08 ± 0.08 cm/y (average from 1.06 ± 0.10 to 0.26 ± 0.04 cm/y after 1963-64), in Bod-dal sub-basin from 0.25 ± 0.09 to 0.08 ± 0.08 cm/y (average 0.61 ± 0.06 to 0.39 ± 0.05 cm/y after 1963-64), and in Gagribal sub-basin from 0.25 ± 0.09 to 0.14 ± 0.03 cm/y (average 0.22 ± 0.05 to 0.14 ± 0.03 cm/y after 1963-64). In case of ^{210}Pb, it is 0.21 cm/y for Nagin sub-basin for sediment core D14 which compares well with the average rate of sedimentation (0.20 cm/y) estimated using ^{137}Cs dating technique. As the rates of sedimentation are very less, the variation in sedimentation rate in the last 10-15 years is not reflected in ^{210}Pb activity measurements. The mean rate of sedimentation in Dal-Nagin

lake have been calculated by using the weighted area method. The average rate of sedimentation in Dal lake is 0.52 ± 0.04 cm/y since 1964 that stands resuced to 0.22 ± 0.03 cm/y since 1987. Similarly the rate of sedimentation in the Nagin lake is 0.41 ± 0.05 cm/y since 1964 and 0.34 ± 0.03 cm/y since 1987.

The rates of sedimentation are higher in the Hazratbal sub-basin as a result of the silt load entering into the lake through Telbal drain. It has been found that the pattern of sedimentation in Dal lake depends more on the distance of sampling points from the Telbal drain vis-a-vis the depth of the lake at the sampling locations. It is also interesting to note that the average rate of sedimentation has reduced considerably (0.58 ± 0.10 cm/y) in Hazratbal sub-basin after 1986-87 in comparison to the rate of sedimentation since 1963-64 (1.60 ± 0.13 cm/y) and 1978-79 (1.0 ± 0.18 cm/y) as seen clearly in case of core D-2. This may be due to the effect of silting basin, which has come into existence from the year 1989. On comparison of ^{137}Cs and ^{210}Pb patterns in different cores, it is found that the core D-1 does not represent the true sedimentary environment. It appears that due to the proximity of the sampling location to Telbal drain, the top portion of the sediment deposit has been eroded as a consequence of flow from the Telbal drain with higher velocity. The effect of silting basin is also reflected in case of useful life of Dal lake estimated by using average rates of sedimentation. The estimated life of Dal lake considering an average rate of sedimentation since 1964 is about 154 ± 12 years while that of Nagin lake is about 315 ± 38 years. However, if we consider the sedimentation rate after 1986-87, the expected useful life of Dal lake is about 364 ± 50 years and that of Nagin lake about 379 ± 33 years. However, the useful lives of Hazratbal and Nagin Sub-basins, estimated using the bathymetric maps prepared Dr. Kundargar, are about 786 ± 86 years and 521 ± 48 years respectively based on the rate of sedimentation prevailing after 1987. The variatin in the estimated life is due to the variation in measured volume or mean depth of the lake in both cases.

It is found that the organic matters contribute about 25-30% in lake sedimentation process. The content of organic matters in different sediment cores reveals that the incoming water to the lake is contributing less than 10% of organic matters and the rest are being contributed by the underwater weeds. It is therefore, important to control the growth of weeds in order to increase the useful life of the lake by atleast 25%.

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1.0 INTRODUCTION

Over the last few years, studies of lake and reservoir sedimentation have become of increasing importance in many aspects of environmental appraisal. Estimate of rates of sedimentation are vital in many schemes involving impoundment for water storage, and empirical measurements can contribute both directly to case studies in progress and indirectly through their role in developing and testing models.

Lake sediments contain radioisotopes from both natural and artificial sources. Natural radioisotopes are generated by cosmic ray interactions of the earth's atmosphere while the artificial radioisotopes have been introduced into the environment as a result of the testing of atomic weapons and accidents involving nuclear power installations. Few radioisotopes of geogenic origin also escape into the atmosphere and later on naturally fallout with the precipitation and other decay processes. Out of all the radioisotopes that occur naturally and artificially in the environment, ^{137}Cs (Cesium-137) and ^{210}Pb (Lead-210) have been found very useful for the dating of the sediments that deposit in the lakes and reservoirs. The natural fall out of ^{137}Cs was found considerable during the years 1953-54, 1957-58, 1963-64, 1978-79, 1986-87 due to testing of various atomic devices and nuclear accidents. The ^{137}Cs activity that appeared during the 1986-87 was caused by the Chernobyl Nuclear Reactor accident while the peak corresponding to 1978-79 is due to atomic devices tested by China. These peaks are used as a marker/indicator for the estimation of rates of sedimentation in water bodies.

2.0 STUDY AREA

The Dal lake, which is the largest fresh water lake in India, is located in the heart of Srinagar town (34°18'N & 74°91'E) at an altitude of 1583 m above mean sea level. Although the lake comprises of several sub-basins and myriad of inter-connecting channels, practically it is divisible into four major sub-basins, viz., Hazratbal, Bod-dal, Gagribal & Nagin.

The total area of the Dal lake catchment is about 314 km^2, which is about twenty times more than the lake area. The post-glacial lake with shallow depth is bound on the southwest by Srinagar town and encompassed on the other sides by gentle slopes at the base of precipitous mountains. It is a typical urban lake, mainly used for the tourist recreation. Fishery and harvesting of economically important water plants are of secondary importance.

A number of ephemeral water channels enter the lake from the human settlements and discharge large quantities of water. It is presumed that within the lake basin itself there are a number of springs, which act as permanent water source to the lake. Towards the southwest side an outflow channel discharges lake water into a link channel connected to Jhelum river. A small canal connects the Nagin basin of the Dal lake with Anchar lake and acts as an additional outflow channel.

2.1 Geology and Geomorphology

There are two school of thoughts regarding the origin of Dal lake. One view holds the lake as a post-glacial relic of shallow depth, which has evolved as a consequence of progressive shrinkage of ancient glacial lake, which existed during Pleistocene period. The other view holds that the lake has been formed in the flood plain of river Jhelum due to river meandering. The Dal lake, like other lakes in the Kashmir valley, lies in the flood plain of Jhelum river, whose broad meanders have cut swampy low lands out of Karewa terraces. The position of the lake shows that it is a buried lake. The asymmetric position of the Jhelum river in the valley along is sufficient proof of the shifting of its course promoted by the strong uplift of the southwestern flank.

The catchment consists of mountain ranges on its north and northeast side and on the other sides it is enclosed by flat arable land. The main geological formations are trap rocks, slate limestone and clayey material. In some parts of the catchment freshly deposited alluvium is also present. Around the lakeshore, the lower land slopes of the catchment have been utilised for paddy cultivation, orchards and gardens. The northern part of the catchment comprises mainly outer suburbs of Srinagar town and is extensively used for paddy cultivation. The northwest catchment has a maximum elevation of 3970 m above m.s.l. (Mahdeo Peak) and ranges along Hayan forest upto Hundoora. The entire catchment is located between 34° 5' to 34° 10' 25"N latitude and 74° 50' E longitude. The upper reaches of this catchment have steep and precipitous rocky slopes, which change to moderate in mid-reaches, formed out of glacial moraines. The lower reaches are somewhat flat, terraced having clay/loam overburden over boulders. These are mostly inhabited and used for agriculture.

3.0 ESTIMATION OF RATES OF SEDIMENTATION

The degradation of Dal- Nagin lake is mainly due to siltation, weed infestation, discharge of domestic sewage, surface runoff carrying pesticides and other chemicals used in agriculture. The overall impact of these activities has resulted in the reduction of lake capacity, deterioration of water quality, ecological changes in the lake and loss of aesthetic value. In addition, catchment deforestation causes topsoil erosion leading to lakebed siltation. It is reported that aproximately 78,944 m^3 silt load enters annually into the Dal lake.

There are a large number of House Boats and Shikaras used for tourism purpose and a sizeable population has come up within the lake area related to these activities, and other temporary and permanent settlements have also come up. The domestic wastes are also disposed into the lake. The aquatic weeds have developed in large amount in the lake and consequently, the organic matters derived mostly from the aquatic weeds contribute at a large scale (about 25%) in the sedimentation in all the sub-basins of the lake.

The Telbal drain that enters the Dal Lake near Habak-Homheir on the northern bank of the lake is a major source of silt inflow to the lake. This drain has two main tributaries viz., Dachigam drain and Dara drain, whose confluence at Muthbag gives rise to Telbal drain. Besides the above, other streams contributing to Telbal drain are Batapora drain, Wanihama drain and Burahama drain which merge with Telbal drain in the lower reaches.

It has been estimated that on an average about 60,000 tons of silt flows into the lake annually through Telbal drain as a direct result of erosion in the denuded catchment area of the Dal lake. Further, the ever-increasing population has resulted in reclamation of marshes into land for habitation, leading to encroachments and putting stress on the lake eco-system. The silt inflow from Telbal drain has also carried nutrients to the lake from the catchment and as per estimates 15 tonnes of phosphate and 322 tonnes of nitrogen are added to the lake system every year, which either gets locked up in the macrophytes or deposited in the already enriched bed sediments (Project Feasibility report prepared by IRAM Consult International for J & K Lakes and Waterways Development authority, Srinagar).

The rates of sedimentation can be estimated using conventional methods like lake sounding method, sediment balance method etc. It can also be measured by remote sensing and isotope techniques with higher accuracy. However, in case of remote sensing technique, the information is obtained on an aggregate level while one can get information on the rates of sedimentation in different parts of a water body using isotope techniques. In the present study, environmental radioisotopes (^{137}Cs and ^{210}Pb) have been used employing radiometric-dating techniques of sediment samples. The details of ^{210}Pb and ^{137}Cs methods for sediment dating are given below.

3.1 ^{210}Pb Method for Sediment Dating

Over the past thirty years, ^{210}Pb dating has developed into a major tool for paleo-limnologists, historians, geographers and environmental scientists. Many techniques are available for collecting sediment cores, ranging from the simple to the quite complex, but all have been shown to give good results. The analytical methods for ^{210}Pb and ^{226}Ra are well established and of sufficient variety that these can be carried out by a competent analyst in any reasonably equipped laboratory.

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.

3.1.1 Analytical techniques

^{210}Pb dating depends on the accurate determination of the level of unsupported ^{210}Pb in a series of sediment samples. In order to do this, the total ^{210}Pb content of each sample is determined initially. The supported ^{210}Pb is then measured by analysis for its precursor and ^{226}Ra and the unsupported ^{210}Pb derived by subtraction of this value from the total ^{210}Pb. Ideally, all sections of a sediment core should be analysed for ^{210}Pb and ^{226}Ra until a depth is reached at which the total ^{210}Pb is indistinguishable from the supported ^{210}Pb. However, for economic reasons this is not normally done and it is usual to determine ^{210}Pb in about 10 sections between the surface and the region where the unsupported ^{210}Pb is no longer detectable. If the ^{226}Ra content is relatively constant, then it is generally sufficient to analyse sections at the top, middle and bottom of the region of interest to establish the supported ^{210}Pb. If the ^{226}Ra is variable however, then all sections analysed for ^{210}Pb must also be analysed for ^{226}Ra.

3.1.2 Determination of ^{210}Pb activity

The direct measurement of ^{210}Pb in sediment by detection of its 47 KeV photon emission has been reported by Gäggeler et al. (1976). This method has the advantage of being non-destructive and the sediment sample can be used for other measurements. However the 47 KeV emission from ^{210}Pb is only present in 4 per cent of its disintegration and the method is relatively insensitive. The limit of detection is about 2 pCi/g for a sample of about 100 g, which seriously limits its application to many cores where the concentration of ^{210}Pb, even in the surface sediments, may be less than 5 pCi/g. In some core sections, the weight of sediment available for analysis is only a few grams and this will further increase the limit of detection. However, the method may well have application in determining the total ^{210}Pb in a core where no profiling is required. In this case, the whole core should be homogenised to take a sufficiently large sample for measurement.

Because of the low energy of its beta emission ^{210}Pb is often determined by means of its ^{210}Bi daughter. This has a half-life of 5 days and emits a beta particle with E_{max} 1.16 MeV. A technique used by many workers (Krishnaswamy et al., 1971 and Koide et al., 1973) for determining ^{210}Pb in sediment is as follows. A sample of dried sediment is leached with hydrochloric acid and then the ^{210}Pb along with the added lead carrier is removed from the resultant solution by anion exchange. The lead is then precipitated, either as sulphate or chromate, and a suitable source prepared for beta counting. The chemical recovery is determined gravimetrically and the source is left for about 5 weeks before counting to allow the ^{210}Bi to equilibrate with its parent ^{210}Pb.

An alternative procedure is to determine the ^{210}Po granddaughter of ^{210}Pb. This has a half-life of 158 days and decays to stable ^{206}Pb, emitting an alpha particle of 5.3 MeV. As deposition rates are generally less than 1 cm/y, the ^{210}Po will be in equilibrium with ^{210}Pb in all but the surface layer. A number of workers have adopted this approach, including Robbins and Edgington (1975), and Krishnaswamy et al. (1980). The basic radiochemical procedure is to add ^{208}Po as a yield tracer, wet oxidise or leach the sediment sample with strong mineral acids, filter off residual solids and convert the solution to one of dilute hydrochloric acid. Polonium nuclides are then spontaneously deposited on silver discs prior to counting by alpha spectrometry. Eakins and Morrison (1983) employed a different procedure, in which ^{210}Po is dry distilled from the sediment as the volatile tetrachloride prior to deposition on silver. There are a number of advantages in determining ^{210}Pb via ^{210}Po. Alpha counting is inherently more sensitive than beta counting and the ^{210}Po can be identified unequivocally. There is no need of any delay between preparation of the source and counting, and the separation of ^{210}Po from sediments is relatively simple.

Another technique for determining ^{210}Pb has been described by Jensen et al. (1977), in which ^{210}Pb is extracted from a sample of ashed sediment with nitric acid and electrodeposited on platinum. After allowing for ingrowth, ^{210}Po is detected by alpha track counting using a plastic detector. This method is very sensitive but lacks the specificity of alpha spectrometry.

3.1.3 Determination of ^{226}Ra activity

There are a number of approaches to determine ^{226}Ra in sediments. If the concentration is fairly high and the sample is large, ^{226}Ra can be determined directly by gamma counting of its decay products.. Radiochemical methods fall in two groups, those using ^{222}Rn emanation technique to detect ^{226}Ra daughters and those resulting in a solid source which is alpha counted.

In ^{222}Rn emanation technique, a solution of ^{226}Ra is first obtained from the sediment either by acid leaching or fusion and subsequent dissolution. The solution is stored in a closed system to allow ingrowth of ^{222}Rn, which is then flushed out with an inert gas into a scintillation cell. The cell is stored for a few hours before being coupled to a photomultiplier tube and then counted. There are different procedures for producing a solid source for alpha counting depending upon the method of obtaining a solution of ^{226}Ra from the sediment. ^{226}Ra is then separated from impurities by a variety of methods before a source is prepared for alpha counting. Koide and Bruland (1975) used ^{226}Ra as a yield tracer, coprecipitating the radium with lead nitrate. The lead is then removed by anion exchange and the radium is further purified by cation exchange. The purified radium is electrodeposited from a 2-propanol electrolyte onto a platinum disc prior to alpha spectrometry. The ^{226}Ra can be coprecipitated with lead sulphate and subsequently with barium sulphate in the presence of ethylene diamine tetra-acetic acid. The barium sulphate is purified by reprecipitation and its alpha activity determined after storing to allow ingrowth of the ^{226}Ra daughter activities.

The chemical recovery is determined using ^{133}Ba as a gamma yield tracer. Joshi and

Durham (1978) coprecipitated ^{226}Ra with lead and barium carriers from strong nitric acid and then separated the barium and ^{226}Ra from lead by ion exchange. The ^{226}Ra is subsequently coprecipitated with barium chromate which is stored prior to alpha counting.

3.1.4 Interpretation of ^{210}Pb profiles

The interpretation of a ^{210}Pb sediment profile and its conversion into one of life versus depth depends on assumptions concerning the supply of ^{210}Pb to the sediment column and its behaviour within it. It is generally assumed that the supply of atmospheric ^{210}Pb to the water surface and the catchment is constant on a time scale of 100-200 years. The flux may vary on time scales of the order of a year but, as sediment sections taken for analysis normally span several years of accumulation, these short-term variations will be smoothed out. It is also assumed that there is no migration or diffusion of ^{210}Pb within the sediment column through the pore water. There is indirect evidence that migration is minimal from the fact that in some profiles there are sharp peaks and inflexions which would be smoothed if migration was significant. Similarly, it is assumed in determining the supported ^{210}Pb that both ^{210}Pb and ^{226}Ra (which is actually measured) are in equilibrium. This has been confirmed from the determination of ^{210}Pb and ^{226}Ra in the lower sections of over a hundred cores where the unsupported ^{210}Pb is no longer detectable. However, Imboden and Stiller (1982) have discussed the influence of ^{222}Rn diffusion on the ^{210}Pb distribution in sediments and have produced a mathematical model to describe the distribution of ^{222}Rn within a core. They believe that in cores having a low unsupported ^{210}Pb content, the assumption that ^{226}Ra and ^{210}Pb are in secular equilibrium should be treated with caution. There may well be a small disequilibrium between ^{210}Pb and ^{226}Ra near the sediment- water interface but, if the unsupported ^{210}Pb is in considerable excess, the effect on dating will be negligible.

3.1.5 Models used for ^{210}Pb profiles interpretation

Two main approaches to the interpretation of ^{210}Pb sediment profiles are currently in use, the constant initial concentration (CIC) model and the constant rate of supply (CRS) model. These often yield similar chronologies for the more recent sediments, but there is sometimes divergence in the time scales relating to deeper deposits. There are no definitive criteria for choosing one model in preference to another. Each sediment profile should be considered in relation to all available data, to other chronologies and, wherever possible, to other sediment cores taken from the same water body.

3.1.6 Constant initial concentration (CIC) model

The ^{210}Pb dating technique was first applied to lake sediments by Krishnaswamy et al. (1971) and to marine sediments by Koide et al. (1973). These and many other workers found that a semi-logarithmic plot of the total ^{210}Pb concentration per unit weight of sediment against depth showed a roughly monotonic decline until a region of unchanging concentration was reached. The region of unchanging concentration is the supported ^{210}Pb maintained by ^{226}Ra within the sediment. Subtraction of the supported ^{210}Pb component from the profile results in the lower curve, which is a plot of the unsupported ^{210}Pb against depth. The unsupported ^{210}Pb decreases exponentially and the slope of the line represents a mean sedimentation rate. By a comparison of the concentration at any depth with that at the surface, the life of the sediment at that depth can be calculated from the equation for radioactive decay, which in this case can be expressed as:-

$$C_d = C_0 e^{-\lambda t} \qquad (1)$$

where, C_d = concentration of ^{210}Pb at depth d

C_0 = concentration of ^{210}Pb at the surface

λ = decay constant for ^{210}Pb (0.031)

t = life of sediment at depth d.

This model assumes that, over the time scale being studied, the concentration of ^{210}Pb in sediment at the mud -water interface has been constant. Because of this, it is often referred to as the constant initial concentration or CIC model. It has been validated for marine sediments by the analysis of varied cores from the Santa Barbara Basin (Koide et al., 1972). In some profiles, a semi-logarithmic plot of the unsupported ^{210}Pb against depth is predominately linear, but the slope decreases near the surface. This is often simply the result of reduced compaction of near-surface sediments and the non-linearity is avoided by plotting the ^{210}Pb concentration against the cumulative dry mass of sediment. This technique has been adopted by many workers and has largely superseded the earlier procedure. Methods for assessing the effects of compaction on the calculation of sediment accumulation rates in the near-surface sediments of a core have been discussed by Robbins and Edgington (1975).

Non-linearity in a ^{210}Pb profile near the surface of a core will also occur if the surface sediments are disturbed. The most common cause of sediment mixing is bioturbation, which normally affects only the top few cm of a core. The redistribution of surface sediments by deposit-feeding organisms has been investigated and found that beneath the zone of mixing, the unsupported ^{210}Pb profile in a core of constant sediment accumulation rate was linear. Bioturbation is normally less in freshwater sediments than those of marine origin, partly because of the small size of the freshwater benthos. Skei (1979), in a study of sediments in the Norwegian fjords, found that anoxic sediments were in general suitable for ^{210}Pb dating but that toxic sediments were often too disturbed by bioturbation.

A further source of non-linearity in a ^{210}Pb profile is a change in the accumulation rate. During the last 50-100 years, the sediment accumulation rate in many water bodies has increased, often due to eutrophication. One of two assumptions is implicit in the use of the CIC model to interpret such a profile:-

(1) There is a large excess of ^{210}Pb in solution in the overlying water and increased sedimentation merely entrains more of the excess. If the sediment has a limited capacity for ^{210}Pb this will result in its concentration remaining constant despite a change in accumulation rate.

(2) The main source of ^{210}Pb in sediment is material uniformly labelled with ^{210}Pb on the catchment and more of this is being transferred to the lake because of environmental change.

Pennington et al. (1976) used the CIC model to interpret non-linear ^{210}Pb profiles of a series of cores from Blelham Tarn. The ^{210}Pb chronology was consistent with both ^{137}Cs and paleomagnetic dating and gave similar ages for visible stratigraphic changes in sediments of different cores. However the use of the CIC model to interpret ^{210}Pb profiles where the sediment accumulation rate is changing does not always yield a chronology consistent with independent time scales and an alternative interpretation has been sought.

3.1.7 Constant rate of supply (CRS) or constant flux (CF) model

In equation (1) discussed under section 3.1.6, C_0=F/R where F is the flux of unsupported ^{210}Pb to the sediment/water interface and R is the sediment accumulation rate. A change in the accumulation rate implies a change in either C_0 or F (or possibly both). The CIC model assumes that C_0 is constant but an alternative approach is to consider that F, the flux of unsupported ^{210}Pb to the sediment, is constant. This is termed the constant rate of supply or CRS model. It was first outlined by Goldberg (1963) and has since been developed by Appleby and Oldfield (1983). The constant flux assumption implies a constant residual of unsupported ^{210}Pb within the sediment column and the life t of sediments at depth d may be calculated from the radioactive decay law expressed as

$$A_d = A_0 e^{-\lambda t} \qquad (2)$$

where A_d is the unsupported ^{210}Pb in the core below depth 'd' and A_0 is the entire unsupported ^{210}Pb below the mud/water interface. The varying sediment accumulation rate r can be calculated from

$$r = A_d / C_d \qquad (3)$$

where C_d is the unsupported ^{210}Pb concentration. Oldfield et al. (1978) have used this model to reassess ^{210}Pb data for several lakes, and have obtained chronologies more consistent with independent dating methods than those obtained using the CIC model. Appleby et al. (1983) have validated the method in freshwater sediments by dating varved cores from Finland and Batterbee et al. (1980) have reassessed the ^{210}Pb chronology of Lake Växjösjön on the basis of a CRS model. The general effect of applying the CRS model is to assign greater ages to sediments at lower depths in a core, whereas there is often reasonable agreement between the chronologies for near-surface sediments. It should be noted that both the CIC and CRS models will give the same chronology if a semi-logarithmic plot of unsupported ^{210}Pb against the cumulative dry mass of sediment is linear. The other model can be a combination of both, i.e., constant initial concentration and constant flux or constant flux and constant rate of sediment (CFCS).

3.1.8 Selection of a model

Although the CRS model has led to a reassessment of many ^{210}Pb sediment profiles, it does not have universal application and it is not always clear which model should be used. Oldfield and Appleby (1983) have found empirically that, if the mean flux of unsupported ^{210}Pb to the sediment falls within the range expected from measured atmospheric fluxes (0.2-1.0 pCi/cm^2/y) the CRS model will give the more valid chronology but, where fluxes are much less than the atmospheric range, results have been poor. Oldfield and Appleby recommend analysis of more than one sediment core wherever possible, to indicate whether sediment resuspension and focusing are occurring. This will lead to reduced unsupported ^{210}Pb at sites where sediment erosion has taken place and enhanced deposits where focusing has occurred. In such cases, although the CRS model will not be valid for a single core, it may be valid for the lake bed as a whole.

The CRS model is used for the near-surface sediments where the accumulation rate may be changing and the CIC model for the deeper sediments where it is constant. If a horizon in a sediment core can be dated independently, for example by ^{137}Cs, pollen or magnetic measurements, or by an input from a known historical event such as ash from a forest fire or a volcano, then the model which gives the best fit to the independent chronology should be used.

3.1.9 Limitations and Uncertainties

In some circumstances it is impossible to date a sediment core by the ^{210}Pb technique, whichever model is used. A very high supported ^{210}Pb content can completely mask the unsupported ^{210}Pb derived from the atmosphere. Occasionally a sediment will have so little unsupported ^{210}Pb that it is difficult to distinguish it from a 'normal' supported ^{210}Pb content.

The reason for a very low unsupported ^{210}Pb content in sediment from a water body where there is no obvious sediment loss is not known, but it may be significant that it has only been observed in lakes with small catchment areas. This suggests that unsupported ^{210}Pb in a lake sediment may be derived predominately from the catchment. Perhaps the biggest uncertainty in ^{210}Pb dating is the extent to which the catchment contributes to the unsupported ^{210}Pb in sediment and this is an area, which warrants further study. A further area of uncertainty lies in the distribution of ^{210}Pb within the various components of sediment. Cooper et al. (1981) in a study of the speciation of radionuclides in sediments and soils found that over 30 per cent of the ^{210}Pb activity was bound to organic matter. There is therefore mounting evidence that ^{210}Pb is associated with organic material in sediments, but further work is required to confirm this.

3.2 ^{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.

3.2.1 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 1986-86 due to Lopnor atomic test of atomic 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.

3.2.2 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 work of Plato and co-workers (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.

3.2.3 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; 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.

3.2.4 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).

3.3 Collection of Sediment Cores and Dating of Sediment Samples

Fourteen sediment cores were collected during December, 1999, from different locations in the Lake (Figure-1) using a gravity corer (inner diameter - 5 cm). Six sediment cores were collected from the Hazratbal sub-basin of the lake (including one from the channel that connects Hazratbal and Nagin sub-basins) since considerable quantity of sediment is brought into the lake by Telbal drain (Figures-2 & 3) in this sub-basin. Rest of the cores were collected from Nagin (3 locations), Bod-dal (3 locations) and Gagribal (2 locations) sub-basins. Efforts were made to cover the maximum possible sedimentary environment like floating gardens (Figure-4), permanently stationed house boats (Figure-5) including inflow points. The length of the cores obtained ranged from 30 to 64 cm (Figure-6). With the help of a adjustable piston rod with silicone packing, 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. The details of loss on ignition (organic matters) in percentage and dry density are given in (Tables-1 to 14 for sediment cores D-1 to D-14 respectively). The plots of loss of ignition versus depth, dry density versus depth, dry density versus loss on ignition are shown in Fig. 7 to 20 . The weight normalised mean loss on ignition of different sediment cores are given in Table 15.

All the sliced core samples from fourteen sediment cores (D-1 to D-14) which cover the maximum sedimentary environment of the lake (Fig. 1) were converted into fine powder form and subjected to ^{137}Cs radiometric dating (radioactivity in Core D-10 could not be measured satisfactorily owing to the problem of high organic content - Fig. 16)). While, due

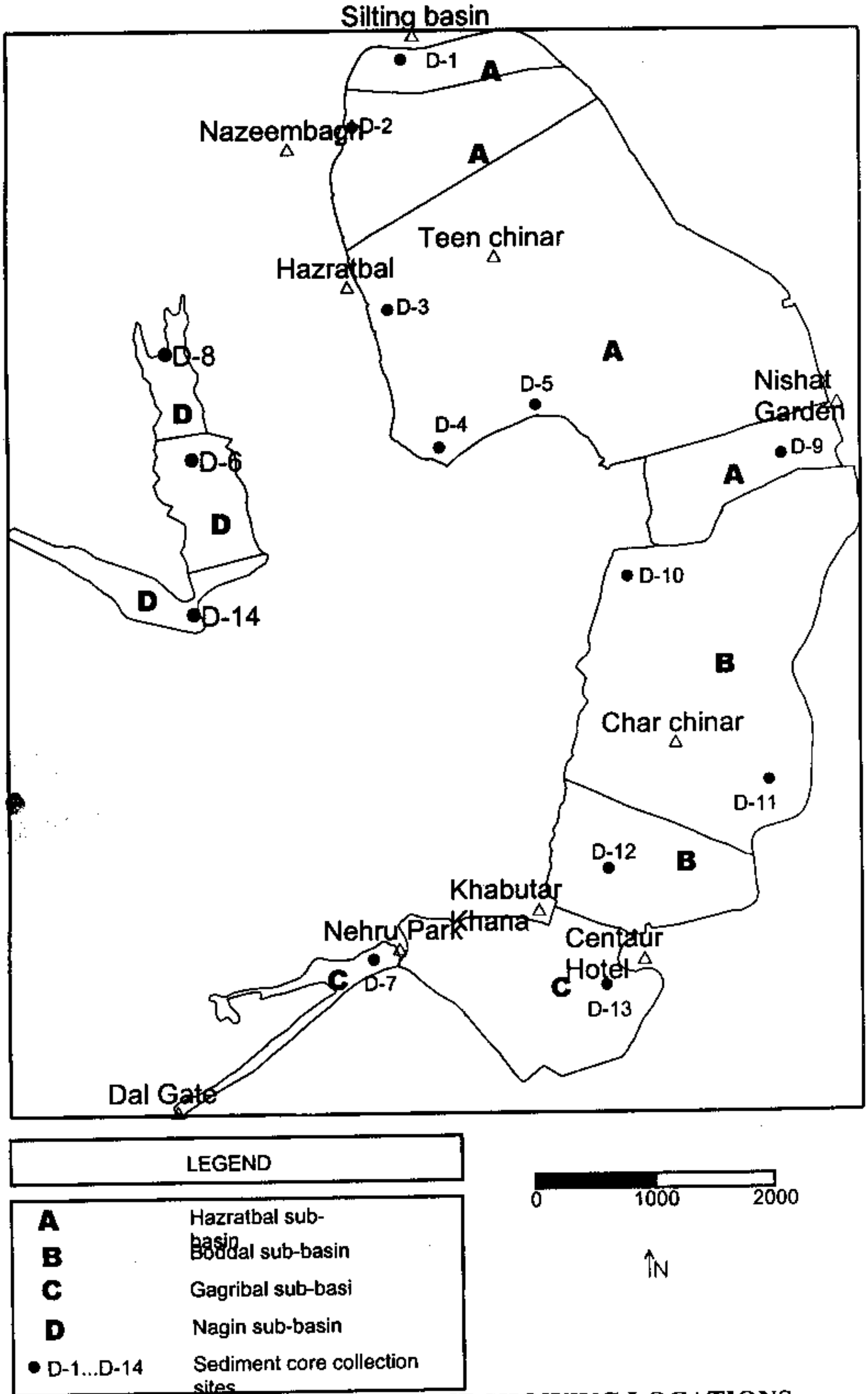

FIG. 1: MAP OF DAL-NAGIN LAKE SHOWING LOCATIONS OF SEDIMENT CORES COLLECTED FROM DIFFERENT SUB-BASINS OF THE LAKE.

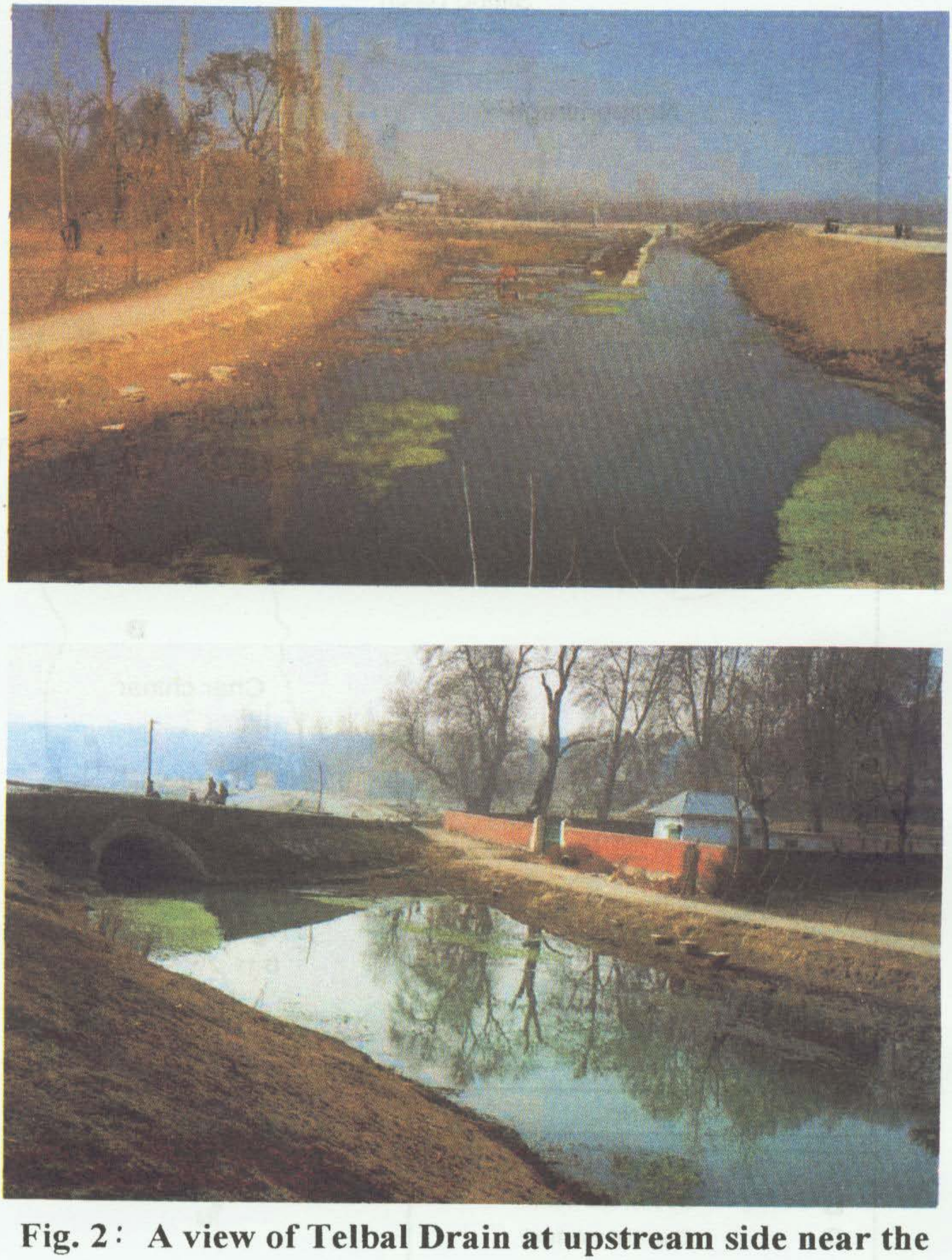

Fig. 2 : A view of Telbal Drain at upstream side near the entry point to Dal - Nagin Lake

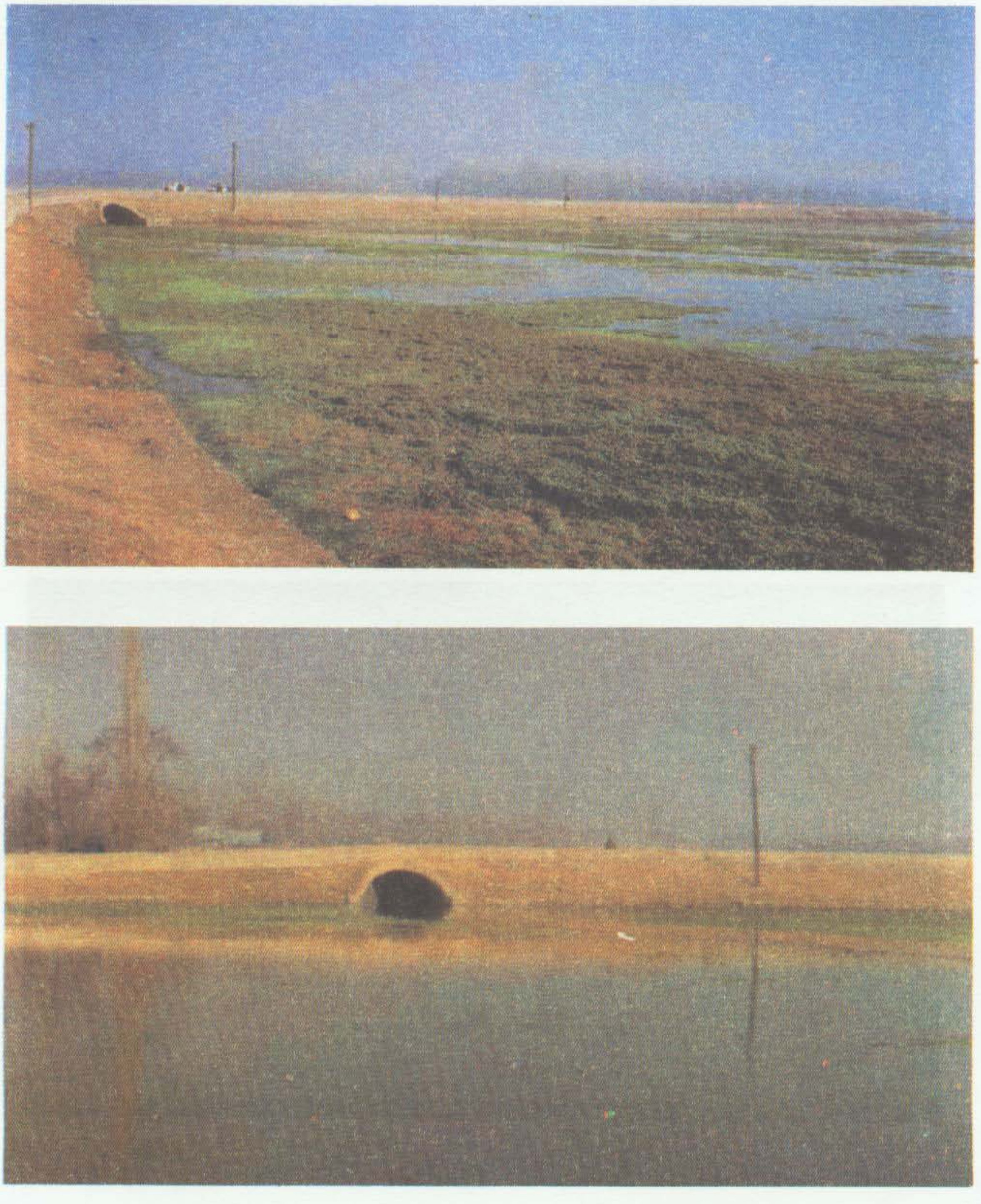

FIG. 3: AVIEW OF DAL - NAGIN LAKE NEAR THE ENTRY POINT OF TELBAL DRAIN TO THE LAKE.

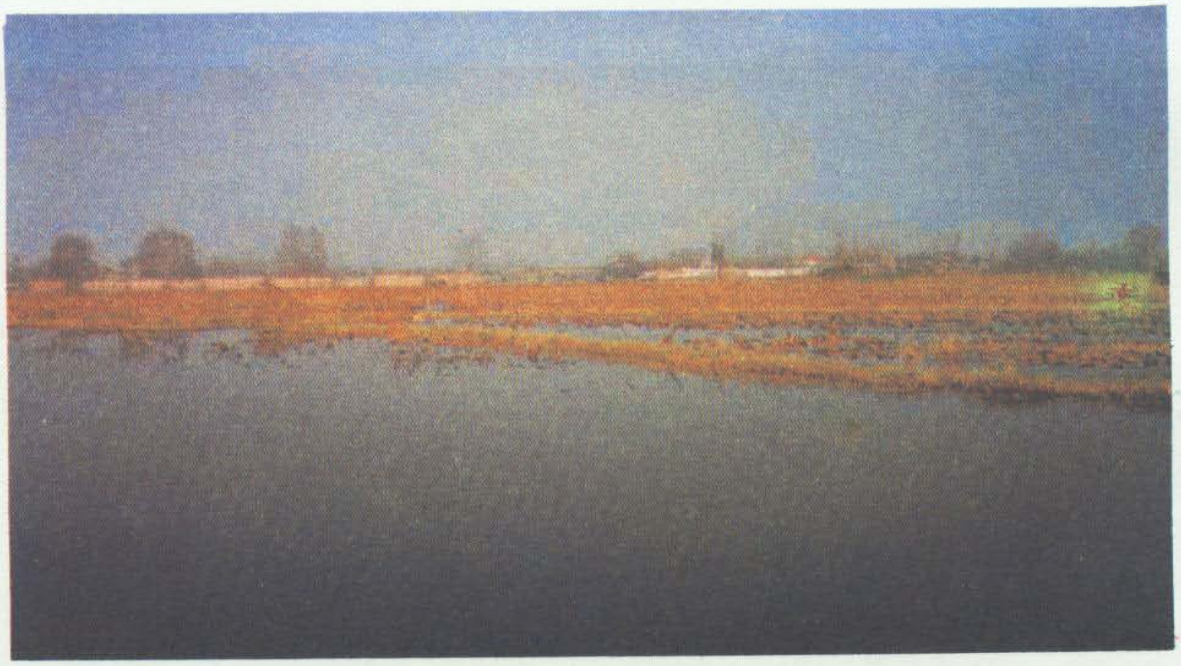

FIG. 4: A VIEW OF FLOATING GARDENS DEVELOPED IN DAL - NAGIN LAKE.

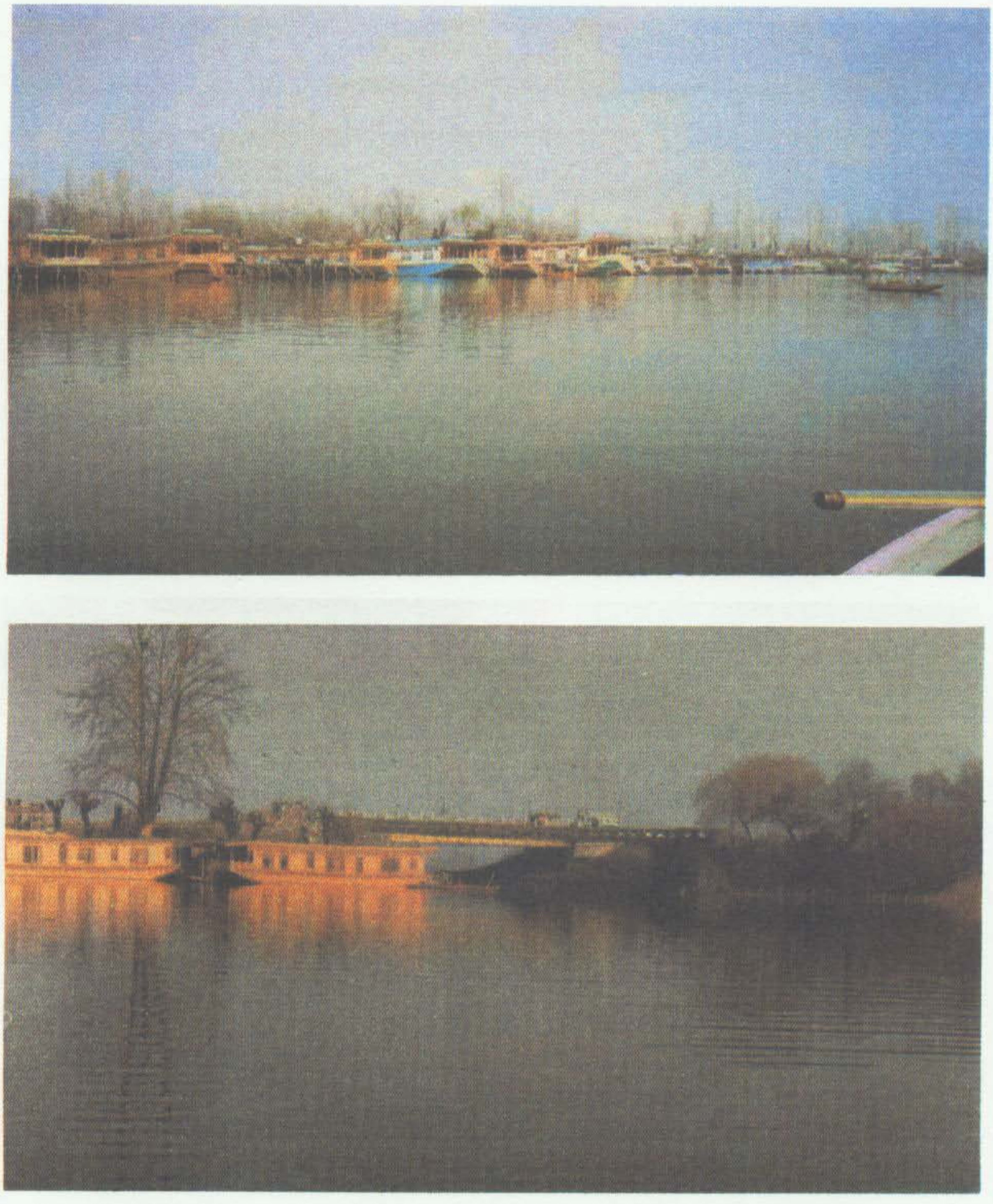

FIG. 5: A VIEW OF HOUSE BOATS PERMANENTLY STATIONED IN DAL - NAGIN LAKE.

FIG. 6: SEDIMENT CORES COLLECTED FROM DAL - NAGIN LAKE.

to high percentage of organic matters only few cores, i.e., D-1, D-2, D-4, D-7, and D-14 could be analysed for ^{210}Pb activity. The Pb-210 activity measured in cores D-1, D2 and D4 is not being reported here as the complete profile of the activity could not be obtained due to washout of top surface layers of core sediments. The washout of top sediment layers in case of core D1 is possible due to its location, near the entry point of Telbal Drain. The high currents of inflowing water during monsoon season may remove the top sediment layers. However, in case of cores D2 and D4, it seems that the anthropological activities in lakes are responsible for disturbing the top layers of sedimemts.The plots of Pb-210 activity for cores D7 and D14 are shown in Fig. 21 and 22 while the estimated rates of sedimentation are given in table-16. The specific details of radioactivity measurements are given below.

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 (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, CRS model has been used for estimating rates of sedimentation.

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, 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 s 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 estimated activities of ^{137}Cs and ^{210}Pb in different sediment cores are given in Tables 1-14 (Appendix-1) while the plots of ^{137}Cs and ^{210}Pb activity with respect to depth are given in Figures-7 to 22.

3.4 Rates of sedimentation in Dal-Nagin Lake

About 355 samples, from the 14 sediment cores collected from the lake have been analysed for ^{137}Cs while about 150 samples have been subjected for various chemical treatments followed by radiometric dating of ^{210}Pb. The rates of sedimentation estimated at different locations and for different time periods are given in Table 16 (Appendix-1). The current rates of sedimentation after 1986-87 obtained by ^{137}Cs shows the following trend of spatial variation .

Hazratbal Sub-basin

From 1.25 ± 0.12 to 0.08 ± 0.08 cm/y (average from 1.60 ± 0.13 to 0.40 ± 0.05 cm/y after 1963-64).

Bod-dal Sub-basin

From 0.25 ± 0.09 to 0.08 ± 0.08 cm/y (average 0.61 ± 0.06 to 0.39 ± 0.05 cm/y after 1963-64).

Gagribal Sub-basin

From 0.25 ± 0.09 to 0.14 ± 0.03 cm/y (average 0.22 ± 0.05 to 0.14 ± 0.03 cm/y after 1963-64).

Nagin Sub-basin

From 0.91± 0.11 to 0.08 ± 0.08 cm/y (average from 1.06 ± 0.10 to 0.26 ± 0.04 cm/y after 1963-64).

In case of ^{210}Pb, it is 0.21 cm/y for Nagin sub-basin for sediment core D14 and 0.13 cm/y for Gagribal for core D7 which compare well with the average rates of sedimentation, 0.20 cm/y and 0.14 ± 0.03 cm/y resectively estimated using ^{137}Cs dating technique. As the rates of sedimentation are small, the variation in sedimentation rate in the last 10-15 years is not reflected in ^{210}Pb activity measurements. The details of the rates of sedimentation estimated at different locations are given in Table-16. The analysis of D5 core did not yield any conclusive results therefore, the rate of sedimentation could not be estimated using the radiometric data of this core.

The mean rate of sedimentation in Dal-Nagin lake have been calculated by using the weighted area method. The average rate of sedimentation in Dal lake is 0.52 ± 0.04 cm/y since 1964 that stands reduced to 0.22 ± 0.03 cm/y since 1987. Similarly the rate of sedimentation in the Nagin lake is 0.41 ± 0.05 cm/y since 1964 and 0.34 ± 0.03 cm/y since 1987.

4.0 COMPUTATION OF LAKE LIFE

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 observed in the rates of sedimentation including the distance of the sampling location from the major inflow point, the different sub-basins of the lake were divided into different zones. The lake life has been estimated taking into account the sediment accumulation rates obtained in all the four sub-basins and the present volume of the lake as per the figures obtained on the basis of bathymetric survey of the lake carried out by RITES, a Govt. of India enterprise, as part of the current project.

The useful life of the Dal-Nagin lake has been estimated by using the area-weighted mean rates of sedimenatation in Dal and Nagin lakes for different time spans (post-1964 and post-1987) and the mean depth of the lake (computed from the available data on the volume and surface area the lake).

The estimated life of Dal lake considering an average rate of sedimentation since 1964 is about 154 ± 12 years while that of Nagin lake is about 315 ± 38 years. However, if we consider the sedimentation rate after 1986-87, the expected useful life of Dal lake is about 364 ± 50 years and that of Nagin lake about 379 ± 33 years. The details of the estimated useful lives of Dal- Nagin lake are given in Table-17.

The useful life of the lake has also been estimated using the bathymetric mapss prepared Dr. Kundargar. The surface area and the volume as estimated by planimetering the maps are presented in Table 18. The estimated useful life of Dal and Nagin lake are 786 ± 86 years and 521 ± 48 years respectively. The details of estimated useful life are given in Table- 17 while the details of computation of countor-wise area, volume between two countors including mean depth of the lake are given in Table-18..

5.0 DISCUSSION AND CONCLUSIONS

The sediment cores collected from different locations in all the four sub-basins comprise of considerable organic matter. The minimum amount of organic matter found in sediment cores collected from the locations near Telbal drain in Hazratbal sub-basin is 4 to 10%, while as we proceed further away from the drain, the percentage of organic matters increases to about 25%. The maximum organic matter has been found to be of the order of 63% (weighted mean 45%) in core D-10 collected from the eastern part of Bod-dal sub-basin. However, if we consider all the sub-basins, it is found that the organic matter contributes to about 25-30% in lake sedimentation process. It reveals that the incoming water to the lake is contributing less than 10% of organic matters and rest of the organic matter is being contributed by the underwater weeds.

The rates of sedimentation are higher in the Hazratbal sub-basin as a result of the silt load entering into the lake through Telbal drain. It has been found that the pattern of sedimentation in Dal lake depends more on the distance of sampling points from the Telbal drain vis-a-vis the depth of the lake at the sampling locations. It is also interesting to note that the average rate of sedimentation has reduced considerably (0.58 ± 0.10 cm/y) in Hazratbal sub-basin after 1986-87 in comparison to the rate of sedimentation since 1963-64 (1.60 ± 0.13 cm/y) and 1978-79 (1.0 ± 0.18 cm/y) as seen clearly in case of core D-2. This may be due to the effect of settling basin, which has come into existence from the year 1989. On comparison of ^{137}Cs and ^{210}Pb patterns in different cores, it is found that the core D-1 does not represent the true sedimentary environment. It appears that due to the proximity of the sampling location to Telbal drain, the top portion of the sediment deposit has been eroded as a consequence of flow from the Telbal drain with higher velocity. The effect of settling basin is also reflected in case of useful life of Dal lake estimated by using average rates of sedimentation. The estimated useful life based on Post-1987 (0.22 ± 0.03 cm/y) rate of sedimentation is about 364 ± 50 y and that based on Post-1964 (0.52 ± 0.04 cm/y) rate of sedimentation is about 154 ± 12 y.

However, the useful lives of Hazratbal and Nagin Sub-basins, estimated using the bathymetric mapss prepared Dr. Kundargar, are about 786 ± 86 years and 521 ± 48 years respectively based on the rate of sedimentation prevailing after 1987. The variatin in the estimated life is due to the variation in measured volume or mean depth of the lake in both cases.

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Table 1: Data pertaining to Core D1 collected at Hazratbal sub-basin near Telbal nala entry point

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	10.00	0.62	0.5
3	10.00	0.24	0.6
5	8.33	0.23	0.5
7	11.67	0.62	0.6
9	11.67	0.73	0.5
11	10.83	0.65	0.6
13	10.83	0.57	0.7
15	8.33	0.69	1.5
17	8.33	0.64	0.7
19	7.50	0.74	1.5
21	10.83	0.71	1.5
23	7.50	0.75	3.1
25	8.33	0.69	3.1
27	9.17	0.68	0.5
29	5.83	0.58	0.6
31	8.33	0.66	0.7
33	11.67	0.67	0.6
35	8.33	0.84	0.6
37	9.17	0.85	0.6
39	8.33	0.78	0.7
41	5.00	0.88	9.3
43	4.17	0.83	1.5
45	3.33	0.91	6.2
47	7.50	0.83	1.5
49	7.50	0.87	0.7
51	5.00	1.00	0.5
53	4.17	0.65	

Table 2: Data pertaining to Core D2 collected at Hazratbal sub-basin between Telbal nala & Hazratbal Mosque

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	11.54	0.37	4
3	8.46	0.33	5
5	6.92	0.49	4
7	8.46	0.67	5
9	9.23	0.59	6
11	6.92	0.65	11
13	6.92	0.59	20
15	6.15	0.50	42
17	13.08	0.52	7
19	10.00	0.64	27
21	10.00	0.56	4
23	10.00	0.62	4
25	7.69	0.65	5
27	8.46	0.66	23
29	7.69	0.81	65
31	10.00	0.69	30
33	8.46	0.62	48
35	6.15	0.64	30
37	9.23	0.70	60
39	10.00	0.58	118
41	8.46	0.58	104
43	8.46	0.73	98
45	9.23	0.75	158

Table 3: Data pertaining to Core D3 collected at Hazratbal sub-basin near Hazratbal shrine

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	17.00	0.10	48
3	12.00	0.20	34
5	15.00	0.10	7
7	17.00	0.22	25
9	22.00	0.25	33
11	19.00	0.21	40
13	35.00	0.18	14
15	32.00	0.21	19
17	22.00	0.17	33
19	17.00	0.06	49
21	16.00	0.07	53
23	37.00	0.10	40
25	41.00	0.13	42
27	43.00	0.10	30
29	42.00	0.08	20

Table 4: Data pertaining to Core D4 collected at Hazratbal sub-basin Nala no. 12

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	18.00	0.10	77
3	21.00	0.13	89
5	23.00	0.16	95
7	20.00	0.11	84
9	18.00	0.13	117
11	18.00	0.15	131
13	17.00	0.15	122
15	18.00	0.15	105
17	18.00	0.14	237
19	14.00	0.18	330
21	10.00	0.18	369
23	10.00	0.30	155
25	10.00	0.26	150
27	14.00	0.20	106
29	14.00	0.25	22
31	16.00	0.23	19
33	20.00	0.15	34
35	20.00	0.19	107
37	19.00	0.17	253
39	12.00	0.15	100
41	13.00	0.19	
43	6.00	0.23	
45	11.00	0.29	

Table 5: Data pertaining to Core D5 collected at Hazratbal sub-basin southern part

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	16.00	0.07	111
3	18.00	0.31	75
5	14.00	0.20	63
7	18.00	0.16	48
9	25.00	0.16	46
11	34.00	0.10	28
13	32.00	0.11	27
15	24.00	0.16	44
17	19.00	0.18	2
19	18.00	0.22	
21	18.00	0.17	12
23	30.00	0.10	18
25	33.00	0.10	
27	31.00	0.09	43
29	35.00	0.10	24
31	36.00	0.09	
33	29.00	0.11	35
35	29.00	0.12	20
37	32.00	0.10	31
39	30.00	0.10	65
41	24.00	0.13	22
43	21.00	0.18	9

Table 6: Data pertaining to Core D6 collected at Nagin lake central part

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	33.00	0.06	58
3	27.00	0.11	143
5	28.00	0.11	40
7	22.00	0.11	51
9	24.00	0.10	128
11	29.00	0.07	21
13	18.00	0.22	28
15	15.00	0.19	
17	14.00	0.18	14
19	19.00	0.18	18
21	22.00	0.16	24
23	24.00	0.19	26
25	26.00	0.16	11
27	26.00	0.14	29
29	27.00	0.17	53
31	24.00	0.09	9
33	25.00	0.16	11
35	26.00	0.17	40
37	26.00	0.16	6
39	28.00	0.18	23
41	28.00	0.16	40
43	34.00	0.16	

Table 7: Data pertaining to Core D7 collected at Gagribal sub-basin near Nehru park

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	24.09	0.12	4
3	23.64	0.15	8
5	22.27	0.15	90
7	25.45	0.18	57
9	22.73	0.20	41
11	21.36	0.28	27
13	25.45	0.31	18
15	27.27	0.28	8
17	31.36	0.29	55
19	27.73	0.42	16
21	22.73	0.54	11
23	16.67	0.73	6
25	16.67	0.81	1
27	15.83	0.95	4
29	15.00	0.83	5
31	7.50	0.99	45
33	9.00	0.87	25
35	8.50	1.07	2
37	7.00	0.73	19

Table 8: Data pertaining to Core D8 collected at Nagin lake northern part

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	20.00	0.11	13
3	17.00	0.20	58
5	16.00	0.21	42
7	17.00	0.13	40
9	19.00	0.14	56
11	17.00	0.16	58
13	20.00	0.12	61
15	21.00	0.16	36
17	21.00	0.14	54
19	21.00	0.16	57
21	19.00	0.15	67
23	20.00	0.12	40
25	17.00	0.15	50
27	19.00	0.14	56
29	18.00	0.18	57
31	20.00	0.13	75
33	19.00	0.17	87
35	20.00	0.17	95
37	23.00	0.14	80
39	23.00	0.14	91
41	25.00	0.19	59

Table 9: Data pertaining to Core D9 collected at Hazratbal sub-basin south-west part

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	5.00	0.00	124
3	26.00	0.11	78
5	28.00	0.11	94
7	24.00	0.09	67
9	26.00	0.07	105
11	26.00	0.14	111
13	24.00	0.12	43
15	22.00	0.15	97
17	19.00	0.15	140
19	22.00	0.16	149
21	23.00	0.19	185
23	15.00	0.19	220
25	18.00	0.16	123
27	25.00	0.17	89
29	30.00	0.13	33
31	27.00	0.17	32
33	24.00	0.15	4
35	28.00	0.19	29
37	28.00	0.18	20
39	30.00	0.12	14
41	33.00	0.15	17
43	24.00	0.18	12
45	35.00	0.13	7
47	34.00	0.13	15
49	18.00	0.32	6
51	16.00	0.40	5
53	13.00	0.41	

Table 10: Data pertaining to Core D10 collected at Bod Dal sub-basin eastern part

Depth(cm)	Loss on Ignition %	Density(g/cc)
1	44.00	0.06
3	46.00	0.03
5	44.00	0.04
7	45.00	0.03
9	40.00	0.06
11	36.00	0.03
13	34.00	0.06
15	36.00	0.08
17	36.00	0.09
19	37.00	0.08
21	42.00	0.08
23	44.00	0.09
25	48.00	0.09
27	49.00	0.08
29	63.00	0.10
31	58.00	0.09
33	38.00	0.08
35	32.00	0.07
37	36.00	0.07
39	34.00	0.07
41	51.60	0.09
43	50.80	0.09
45	52.00	0.09
47	50.80	0.10
49	52.50	0.09
51	52.81	0.08
53	48.13	0.10
55	47.19	0.11

Table 11: Data pertaining to Core D11 collected at Bod Dal sub-basin southern part

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	29.00	0.07	52
3	29.00	0.08	49
5	27.00	0.08	45
7	35.00	0.15	16
9	20.00	0.10	97
11	20.00	0.14	43
13	26.00	0.06	45
15	26.00	0.19	23
17	27.00	0.13	43
19	26.00	0.15	20
21	28.00	0.14	20
23	32.00	0.13	12
25	32.00	0.13	28
27	29.00	0.13	21
29	25.00	0.12	21
31	23.00	0.15	23
33	28.00	0.16	21

Table 12: Data pertaining to Core D12 collected at Bod Dal sub-basin eastern part

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	25.00	0.06	125
3	25.00	0.06	175
5	26.00	0.12	86
7	25.00	0.09	152
9	22.00	0.06	161
11	23.00	0.13	193
13	23.00	0.09	279
15	23.00	0.14	279
17	20.00	0.13	246
19	14.00	0.16	272
21	15.00	0.14	252
23	17.00	0.17	194
25	22.00	0.16	94
27	25.00	0.13	71
29	26.00	0.11	34
31	28.00	0.09	56
33	32.00	0.13	75
35	36.00	0.12	59
37	33.00	0.13	33
39	33.00	0.20	20

Table 13: Data pertaining to Core D13 collected at Gagribal sub-basin eastern part

Depth(cm)	Loss on Ignition %	Density(g/cc)	Cs-137 (mBq/g)
1	30.00	0.09	196
3	30.00	0.10	218
5	30.00	0.11	182
7	33.00	0.09	231
9	30.00	0.11	222
11	42.00	0.09	165
13	27.00	0.13	11
15	27.00	0.06	114
17	23.00	0.21	73
19	27.00	0.14	29
21	27.00	0.12	34
23	31.00	0.14	32
25	31.00	0.14	25
27	28.00	0.14	5
29	28.00	0.15	16
31	27.00	0.15	17
33	45.00	0.06	167
35	24.00	0.16	15
37	26.00	0.24	
39	29.00	0.15	28
41	36.00	0.15	86

Table 14: Data pertaining to Core D14 collected at Nagin lake south extension

Depth(cm)	Loss on Ignition	Density(g/cc)	Cs-137 (mBq/g)	Pb-210 (mBq)
1	30.00	0.09	244	411
3	25.29	0.10	10	306
5	22.94	0.09	144	
7	24.12	0.14	286	189
9	25.88	0.09	154	272
11	25.29	0.12	10	71
13	24.71	0.14	11	33
15	25.88	0.16	12	52
17	24.12	0.16	11	33
19	24.71	0.18	10	16
21	24.71	0.20	27	27
23	21.18	0.23	21	22
25	23.53	0.17	11	23
27	22.94	0.18	10	38
29	20.00	0.21	10	16
31	21.76	0.20	10	19
33	20.59	0.26	11	0
35	23.45	0.22	10	1
37	18.00	0.28	10	0
39	16.73	0.32	13	0
41	39.27	0.40		

Table 15: Weight normalised loss on ignition (organic matter) in different sediment cores

Core-ID	Mean LOI%
D1	8
D2	9
D3	25
D4	15
D5	24
D6	24
D7	16
D8	20
D9	23
D10	45
D11	27
D12	25
D13	29
D14	24

Table 16 : Depth of occurrence of ^{137}Cs peak activities for different years and the estimated rates of sedimentation.

Core-ID		1954	1958	1964	1978/79	1986/87
D-1	Peak depth	-	-	41	24	15
	Rate (cm/y)	-	-	1.13±0.10	1.13±0.19	1.25±0.12
D-2	Peak depth	-	-	39	15	7
	Rate (cm/y)	-	-	1.60±0.13	1.00±0.18	0.58±0.10
D-3	Peak depth	-	-	21	11	1
	Rate (cm/y)	-	-	0.40±0.05	1.25±0.20	0.08±0.08
D-4	Peak depth	-	-	21	11	3
	Rate (cm/y)	-	-	0.66±0.08	1.00±0.18	0.25±0.09
D-6	Peak depth	-	-	9	-	3
	Rate (cm/y)	-	-	0.26±0.04	-	0.25±0.09
D-7	Peak depth	31	17	5	-	-
	Rate (cm/y)	3.50±0.91	2.00±0.37	0.14±0.03	-	0.14±0.03
	^{210}Pb rate (cm/y)	-	-	0.13	-	0.13
D-8	Peak depth	-	-	35	19	11
	Rate (cm/y)	-	-	1.06±0.10	1.00±0.18	0.91±0.11
D-9	Peak depth	-	-	23	10	1
	Rate (cm/y)	-	-	0.87±0.09	1.13±0.19	0.08±.08
D-11	Peak depth	-	-	9	-	1
	Rate (cm/y)	-	-	0.39±0.05	-	0.08±0.08
D-12	Peak depth	-	-	14	-	3
	Rate (cm/y)	-	-	0.61±0.06	-	0.25±0.09
D-13	Peak depth	-		8	-	3
	Rate (cm/y)	-		0.22±0.05	-	0.25±0.09
D-14	Peak depth	-	-	7	-	1
	Rate (cm/y)	-	-	0.26±0.04	-	0.08±0.08
	^{210}Pb rate (cm/y)	-	-	0.21	-	0.21

Table 17 : Estimated Life of Dal-Nagin Lake.

Based on RITES/UOR Data	Dal lake	Nagin lake
Volume (m^3)	10570470	988090
Area (m^2)	13224250	763400
Mean depth (m)	0.80	1.29
Post-1964 rate of sedimentation (cm/y)	0.52 ± 0.04	0.41 ± 0.05
Post-1987 rate of sedimentation (cm/y)	0.22 ± 0.03	0.34 ± 0.03
Estimated life (y) [post-1964 rate]	154 ± 12	315 ± 38
Estimated life (y) [post-1987 rate]	364 ± 50	379 ± 33

Based on Dr. Kundargar's Maps	Dal lake	Nagin lake
Volume (m^3)	12491846	1946923
Area (m^2)	7165085	1086486
Mean depth (m)	1.74	1.79
Post-1964 rate of sedimentation (cm/y)	0.52 ± 0.04	0.41 ± 0.05
Post-1987 rate of sedimentation (cm/y)	0.22 ± 0.03	0.34 ± 0.03
Estimated life (y) [post-1964 rate]	338 ± 24	440 ± 57
Estimated life (y) [post-1987 rate]	786 ± 86	521 ± 48

Table 18: Estimation of volume and mean depth of Dal-nagin lake using Dr. Kundargar's maps

Lake ID	Depth Contour	Planimeter reading						Interval	Volume
		1	2	3	Avg	Scale	Area		
Hazratbal	Scale								
	0	40	41	42	41.00	6097.560976	3365854		
	1.5	549	553	554	552.00		2489837	1.5	4375294
	2	408	410	407	408.33		1776423	0.5	1061559
	3	291	289	294	291.33		284553	1	923984
	3.75	47	46	47	46.67		25	0.75	71811
Boddal	Scale								
	0	20	19	19	19.33	12931.03448	3237069		
	1.5	251	250	250	250.33		1948276	1.5	3848330
	2	148	151	153	150.67		1262931	0.5	796636
	2.7	98	98	97	97.67		357759	0.7	535003
	3	28	28	27	27.67		5	0.3	35910
Gagribal	Scale								
	0	63	61	61	61.67	4054.054054	562162		
	1.5	139	139	138	138.67		352703	1.5	680073
	2	87	87	87	87.00		185135	0.5	132229
	2.5	46	46	45	45.67		5	0.5	31017
						Total Volume (m^3)			12491846
						Total surface area (m^2)			7165085
						Mean depth (m)			1.743
Nagin	Scale								
	0	63	61	61	61.67	4054.054054	1086486		
	1.9	269	267	268	268.00		463514	1.9	1431111
	2.8	115	115	113	114.33		197297	0.9	288965
	4.5	49	48	49	48.67		56757	1.7	203929
	5.7	14	13	15	14.00		5	1.2	22918
						Total Volume (m^3)			1946923
						Total surface area (m^2)			1086486
						Mean depth (m)			1.792

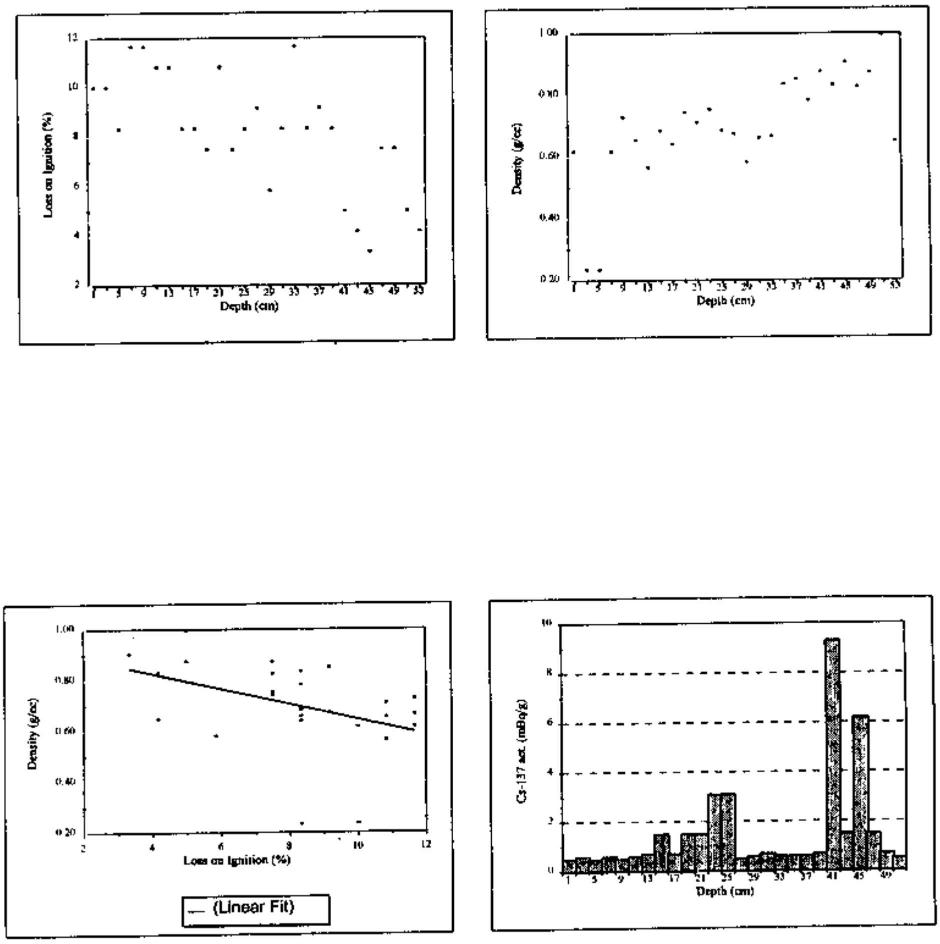


FIG. 7: CORE ID - D1 HAZRATBAL SUB-BASIN NEAR TELBAL NALA ENTRY POINT

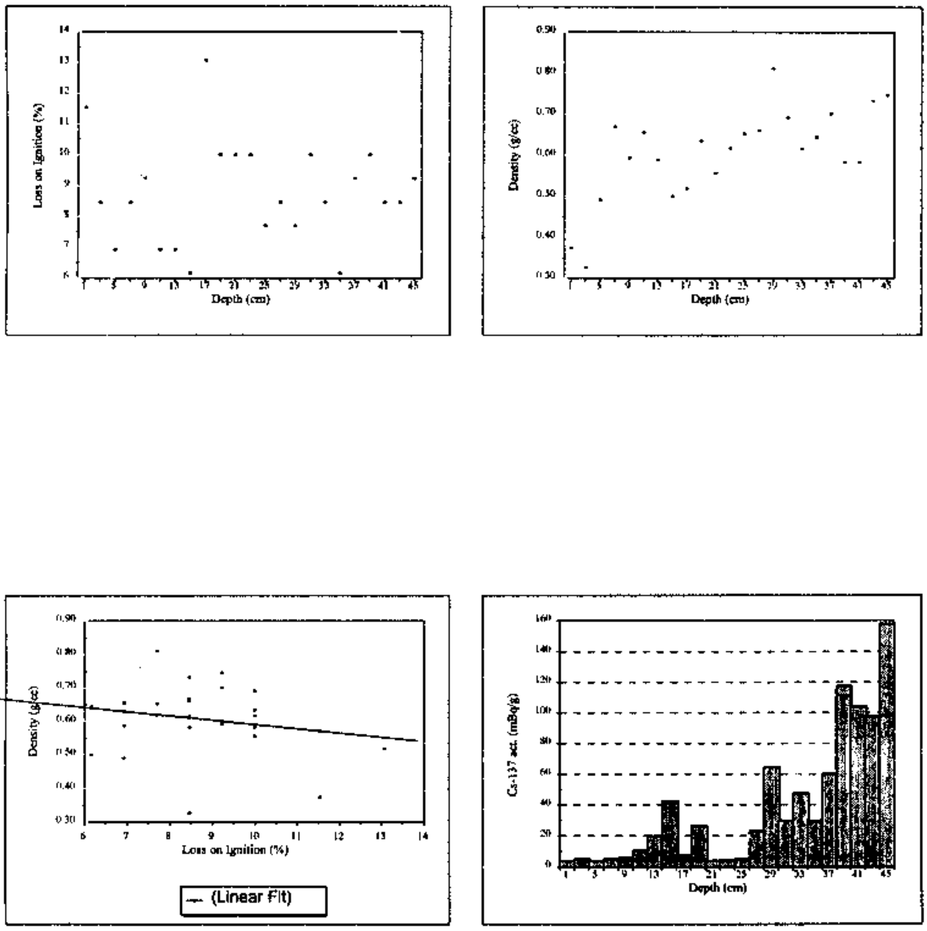


FIG. 8: CORE ID - D2 BETWEEN TELBAL NALA AND HAZRATBAL MOSQUE

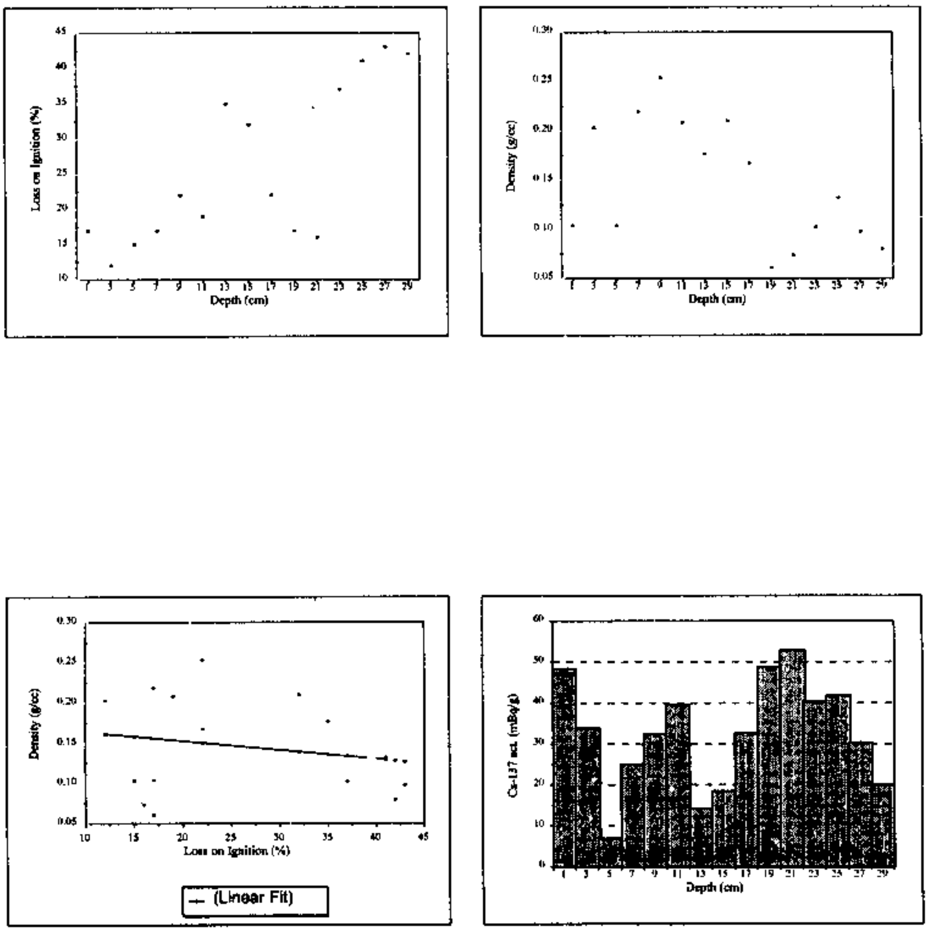


FIG. 9: CORE ID - D3 NEAR HAZRATBAL SHRINE

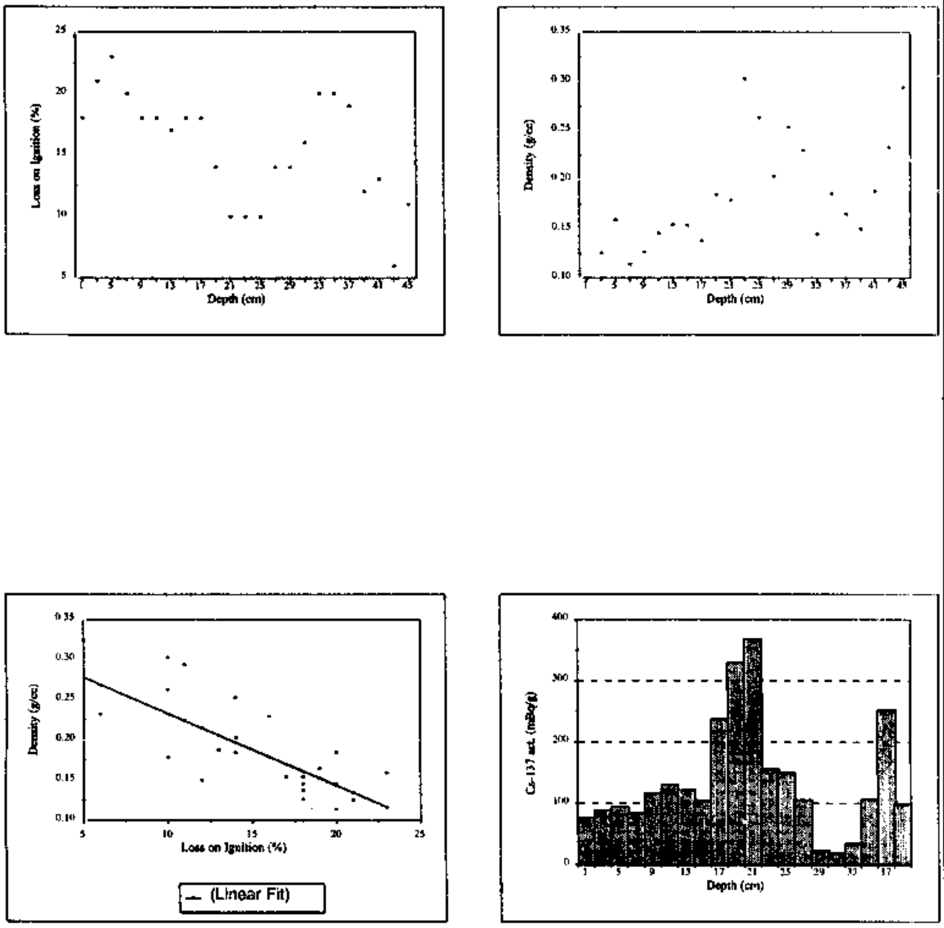


FIG. 10 CORE ID - D4 HAZRATBAL SUB-BASIN NALA NO. 12

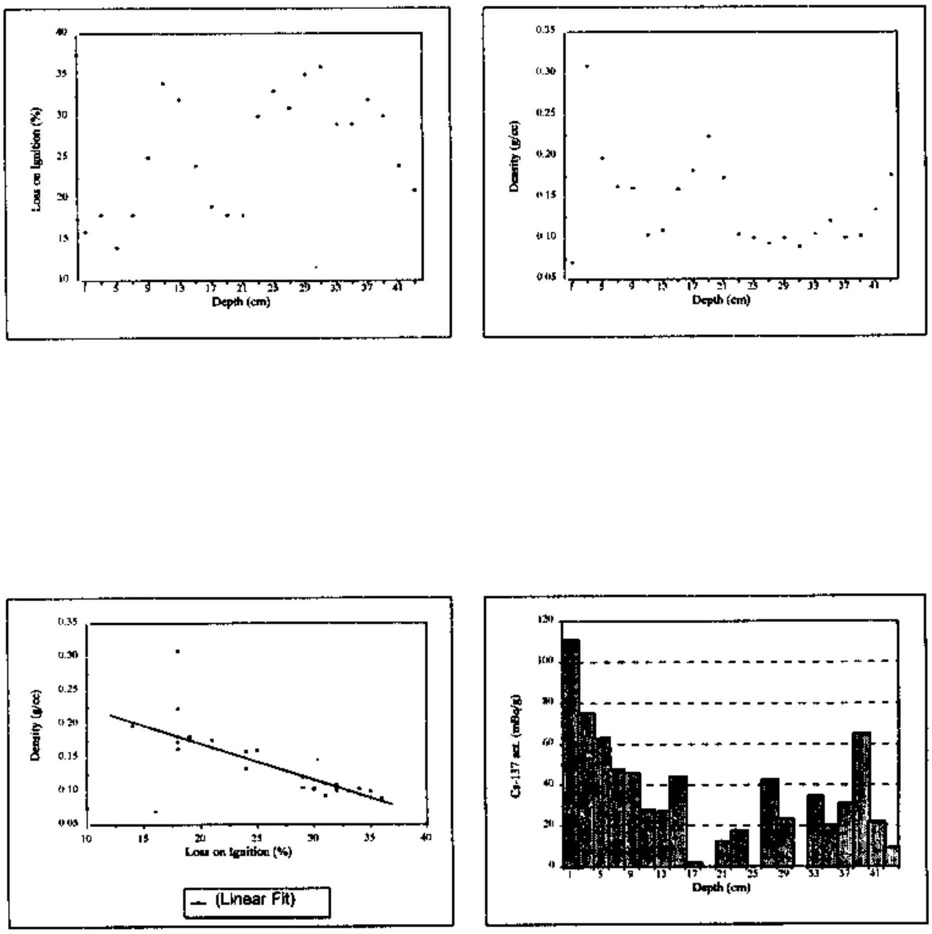


FIG. 11: CORE ID - D5 HAZRATBAL SUB-BASIN SOUTHERN PART

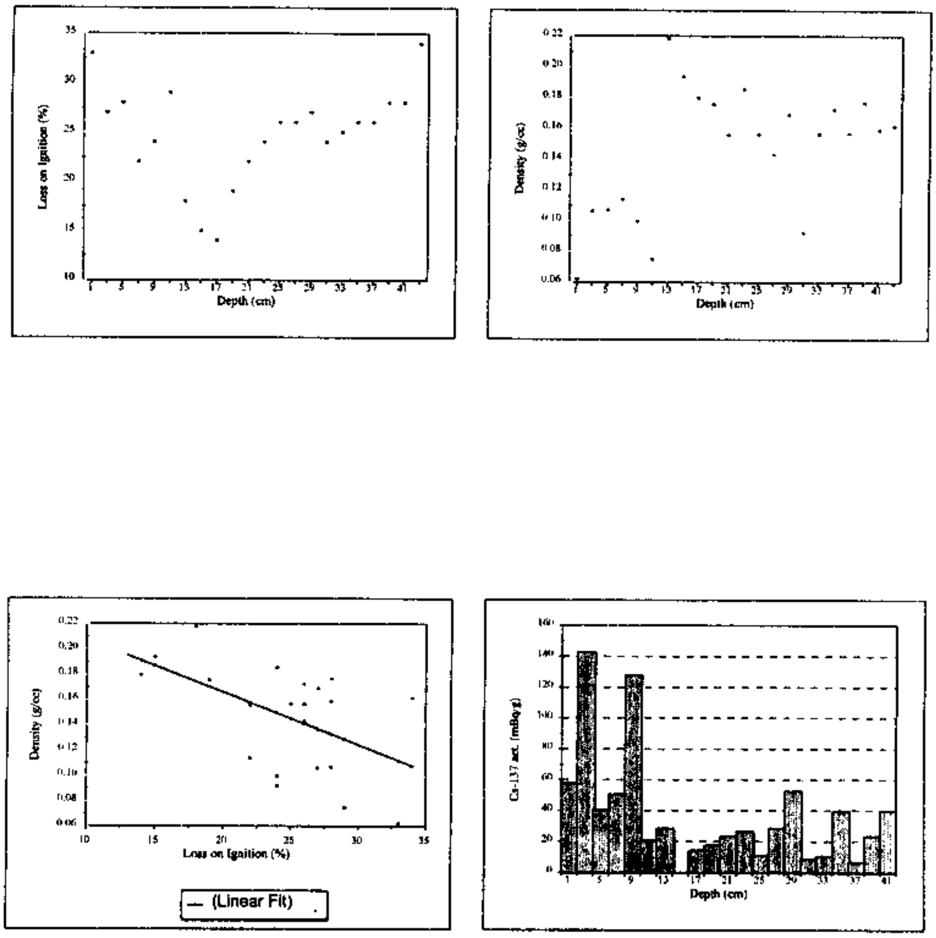


FIG. 12: CORE ID - D6 NAGIN LAKE CENTRAL PART

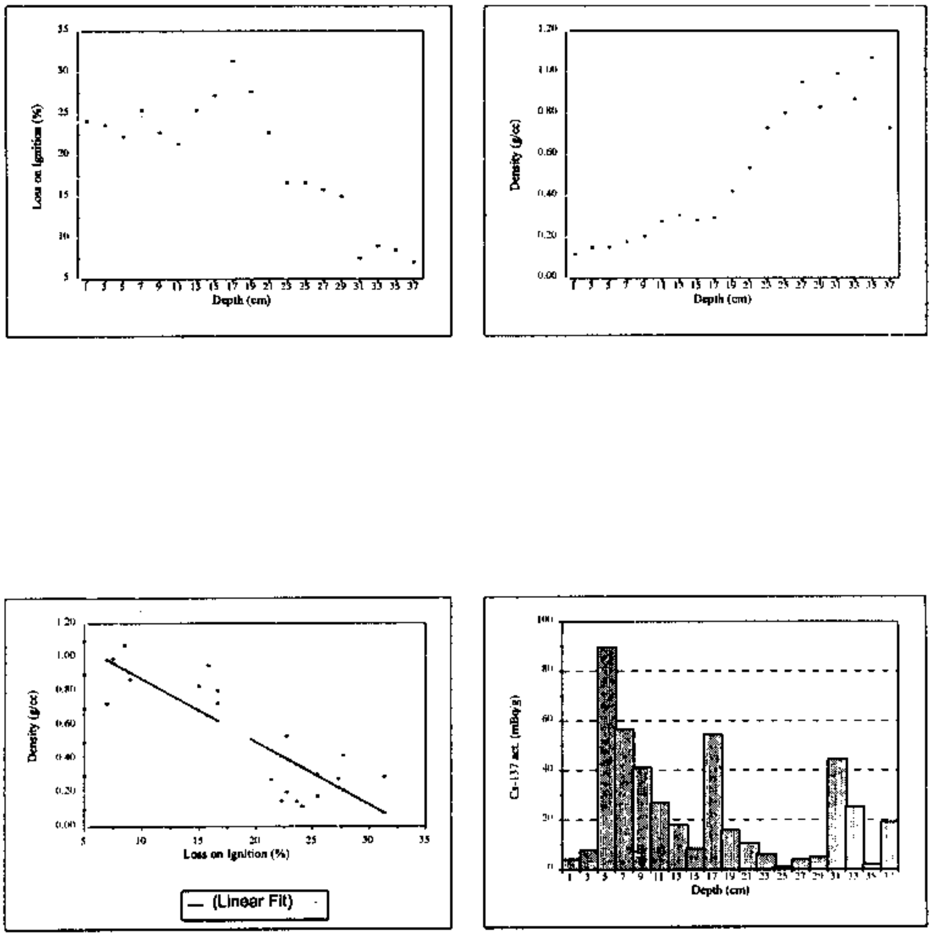
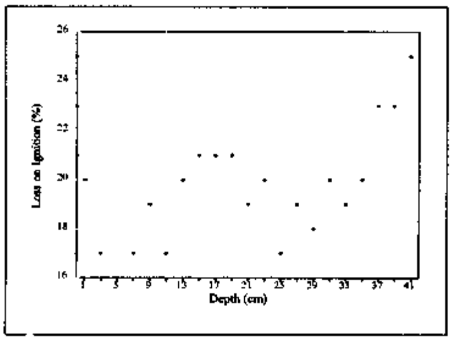
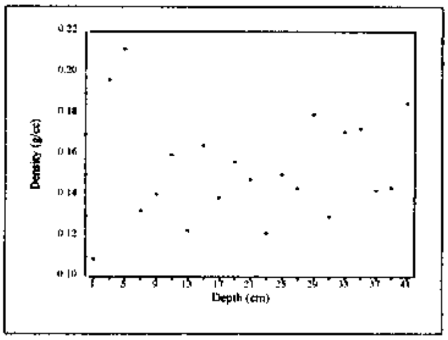
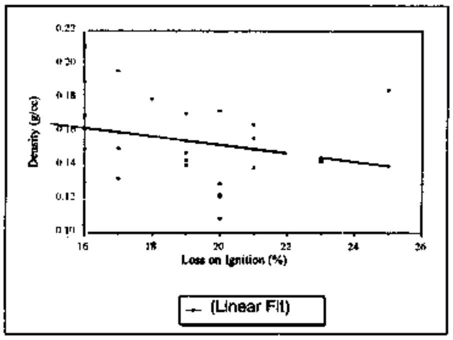


FIG. 13: CORE ID - D7 GAGRIBAL SUB-BASIN NEAR NEHRU PARK







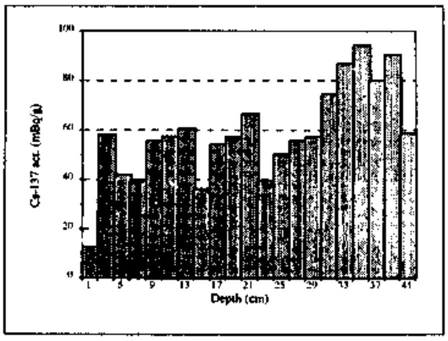


FIG 14: CORE ID - D8 NAGIN LAKE NORTHERN PART

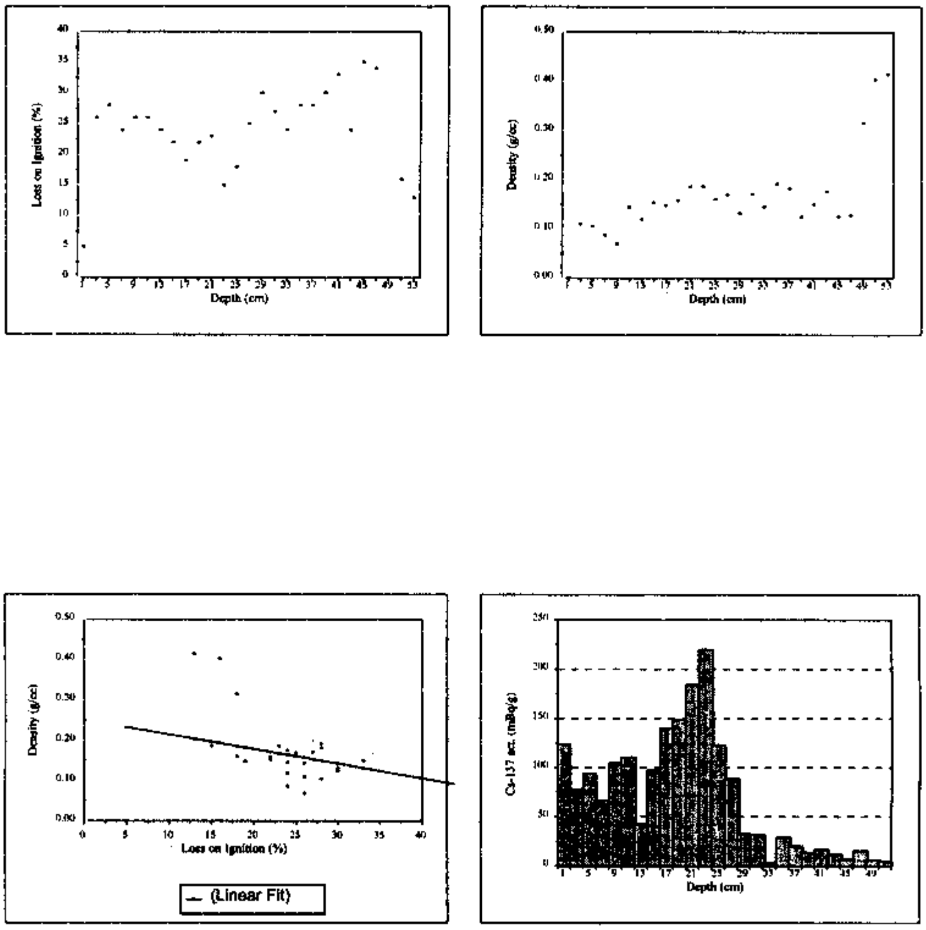


FIG. 15: CORE ID - D9 HAZRATBAL SUB-BASIN SOUTH-WEST PART

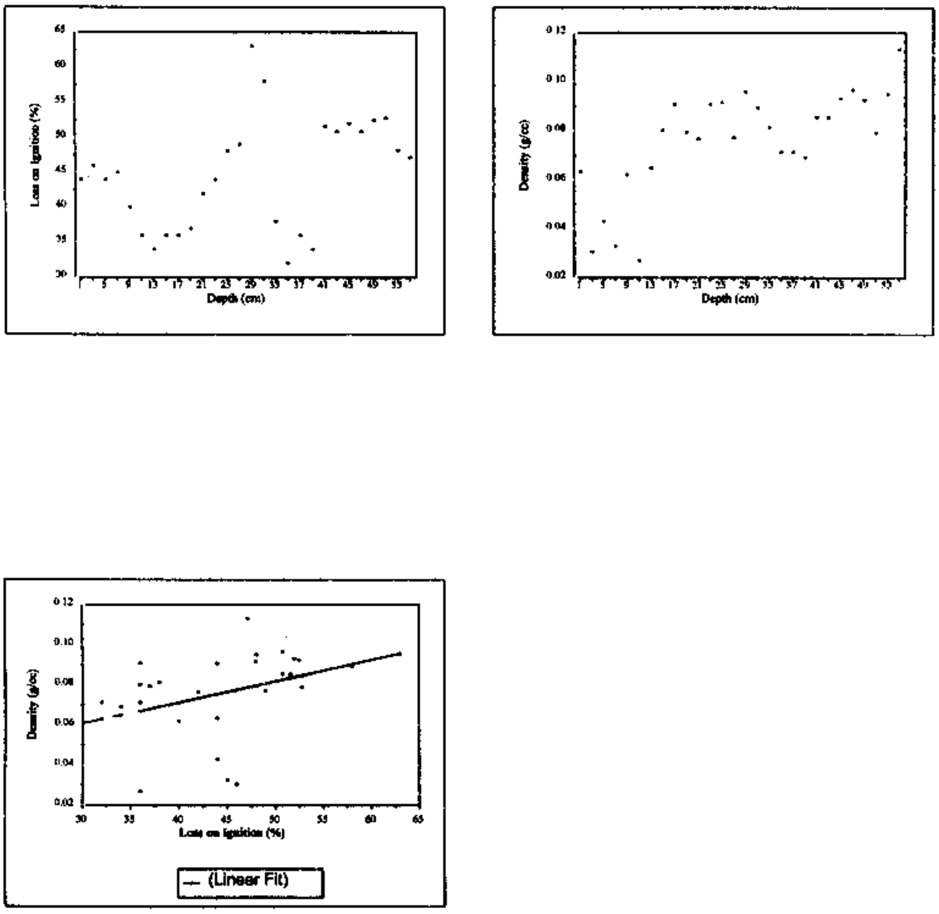


FIG. 16 CORE ID - D10 LOCATION - NEAR EASTERN PART

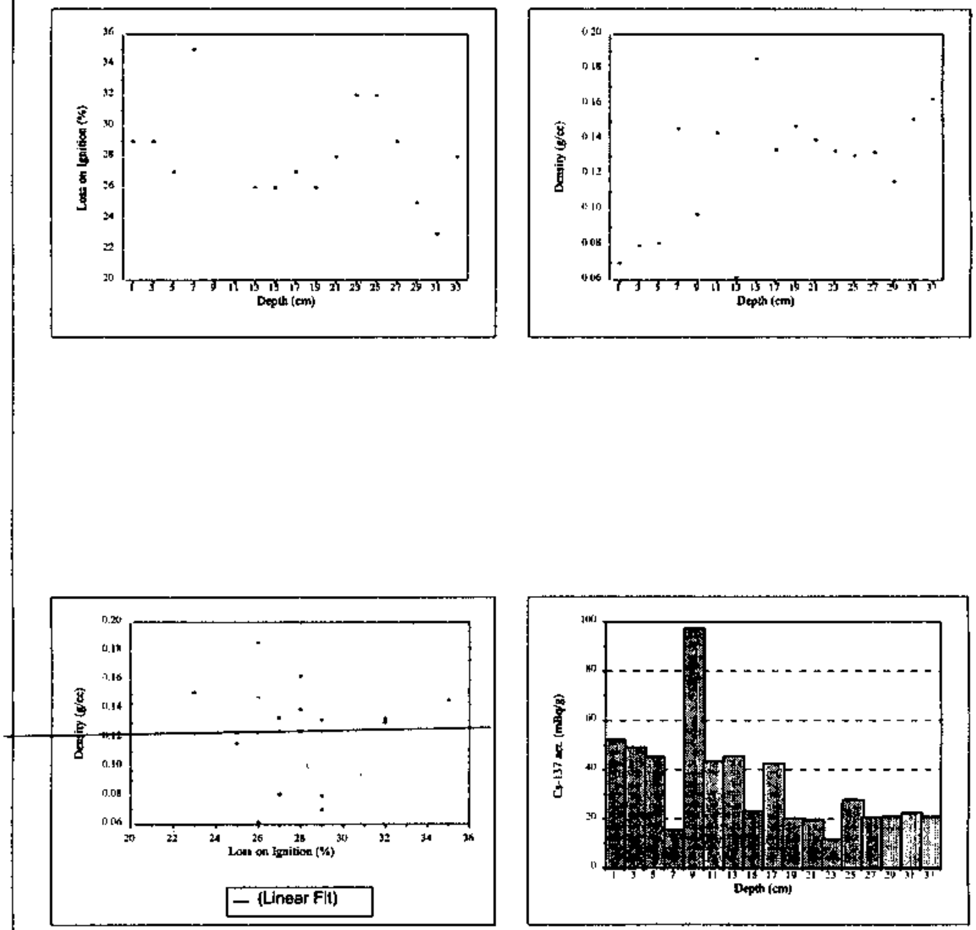


FIG. 17: CORE ID - D11 BOD DAL SUB-BASIN SOUTHERN PART

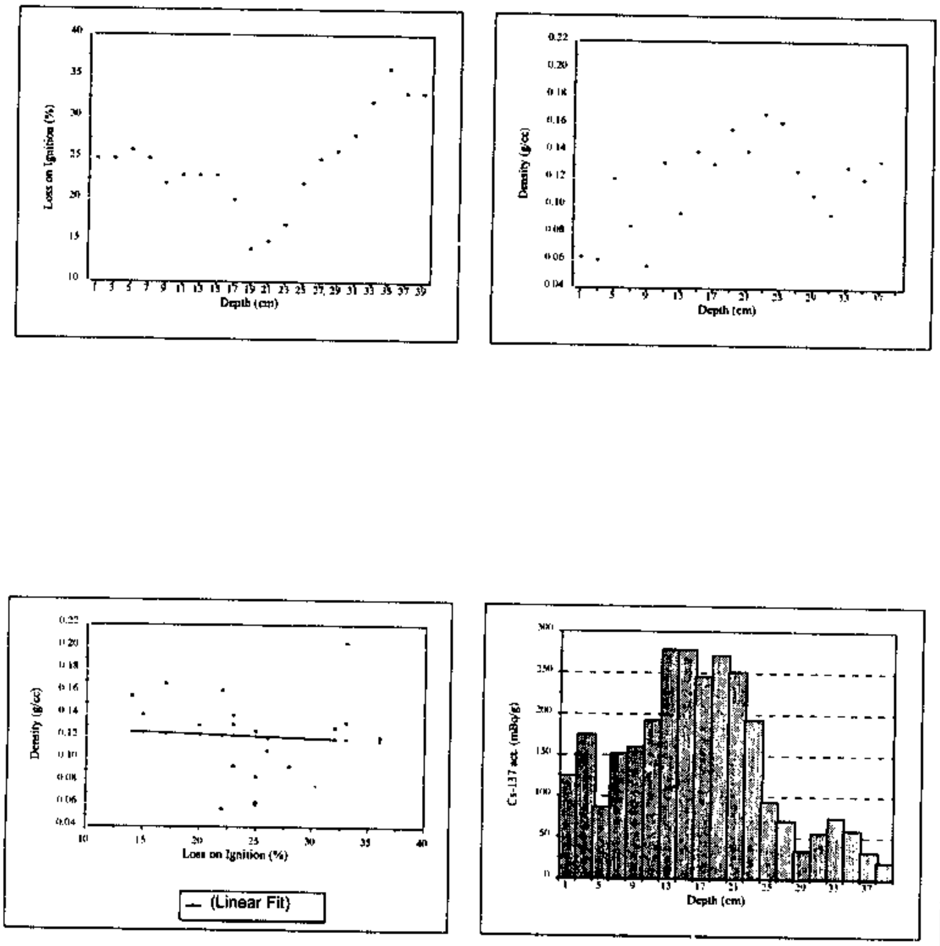


FIG. 18: CORE ID - D12 BOD DAL SUB-BASIN EASTERN PART

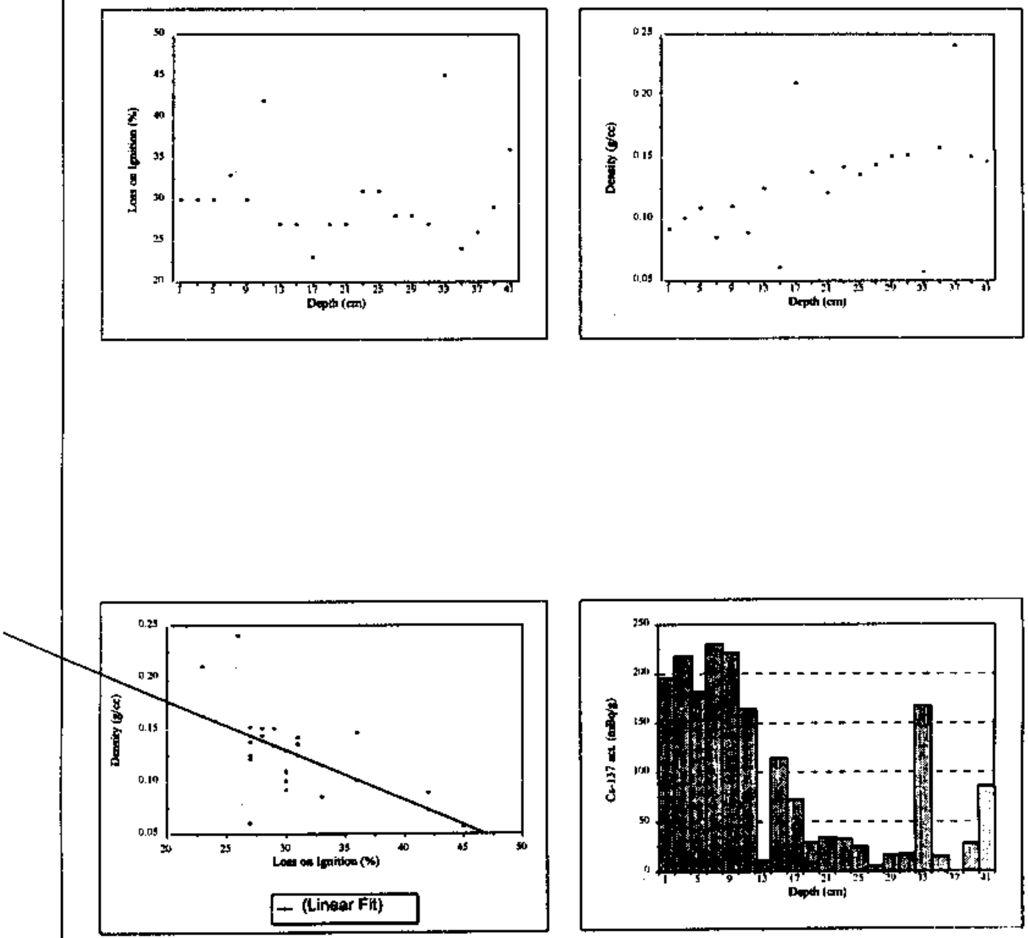


FIG. 19: CORE ID - D13 GAGRIBAL SUB-BASIN EASTERN PART

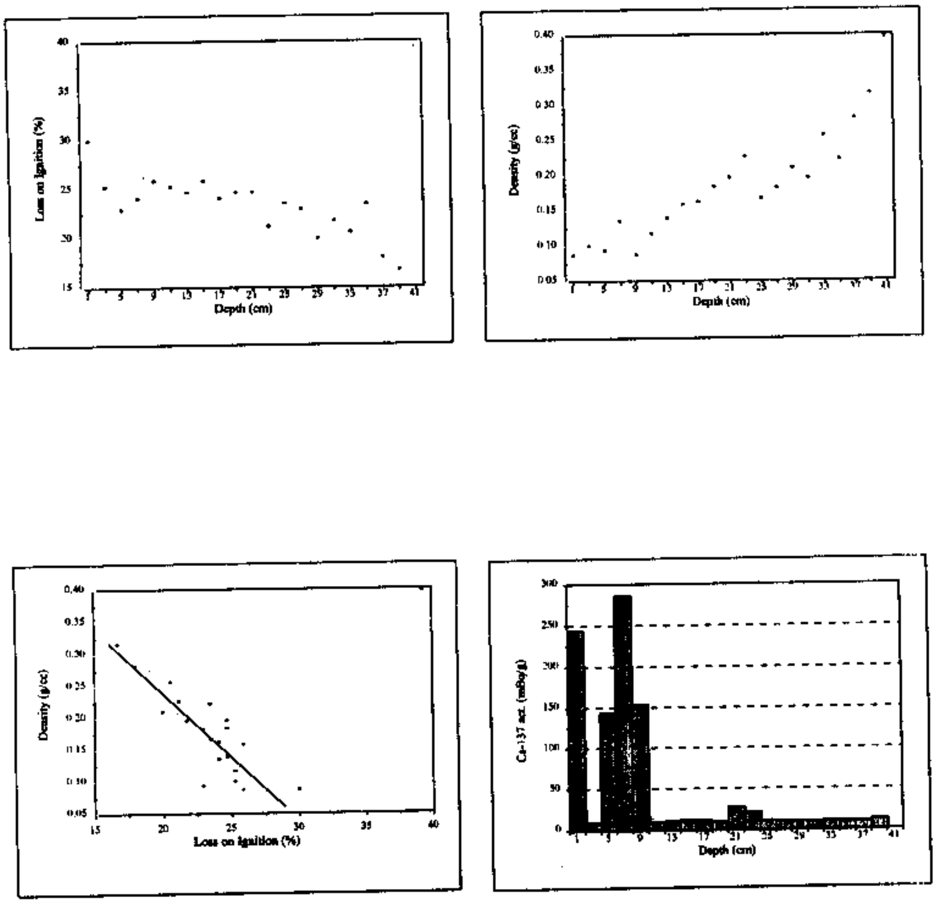


FIG. 20: CORE ID - D14 NAGIN LAKE SOUTH EXTENSION

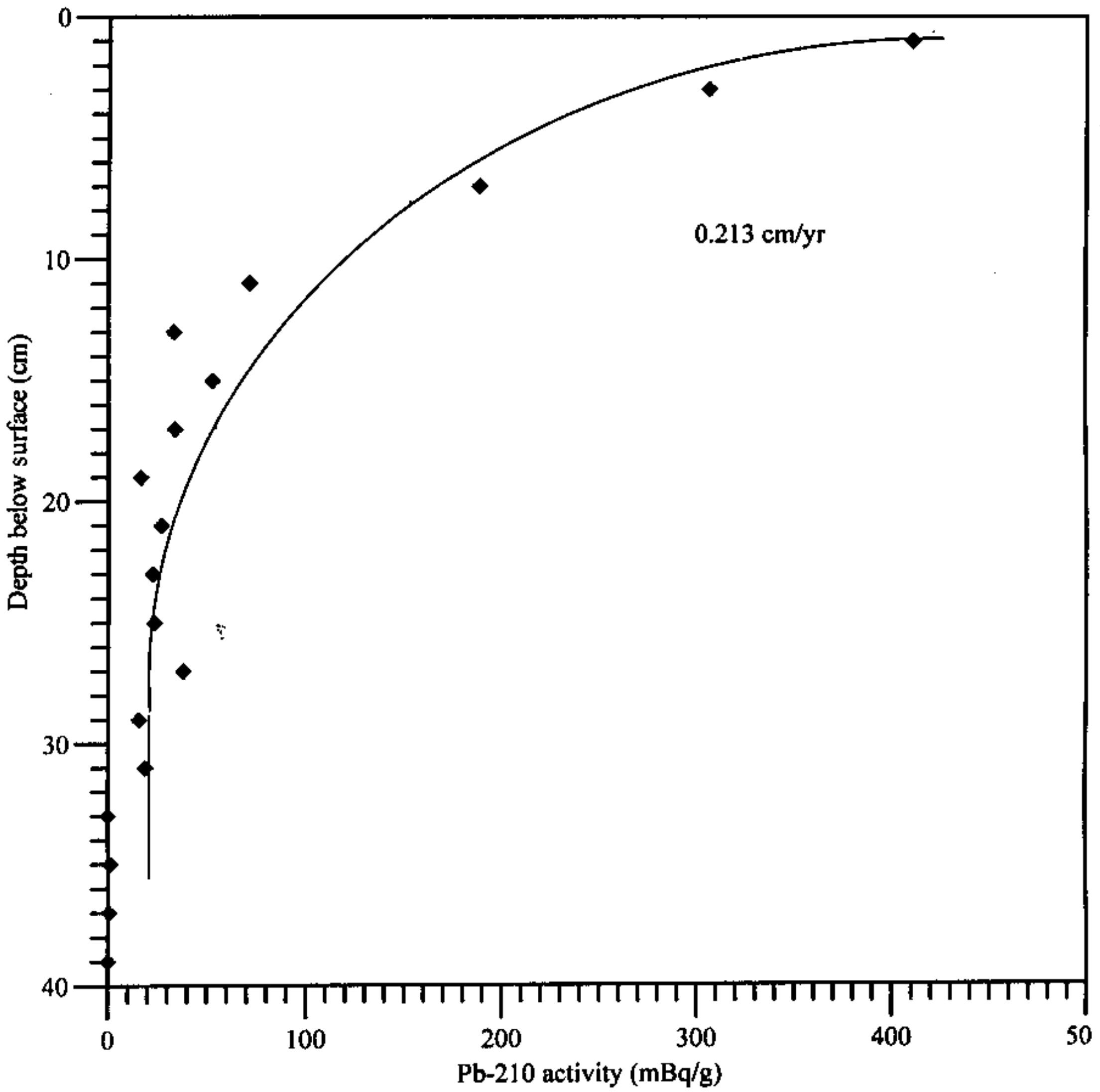


FIG. 21: ^{210}Pb ACTIVITY IN SEDIMRNT CORE D14 (LOCATION NAGIN LAKE SOUTH EXTENSION)

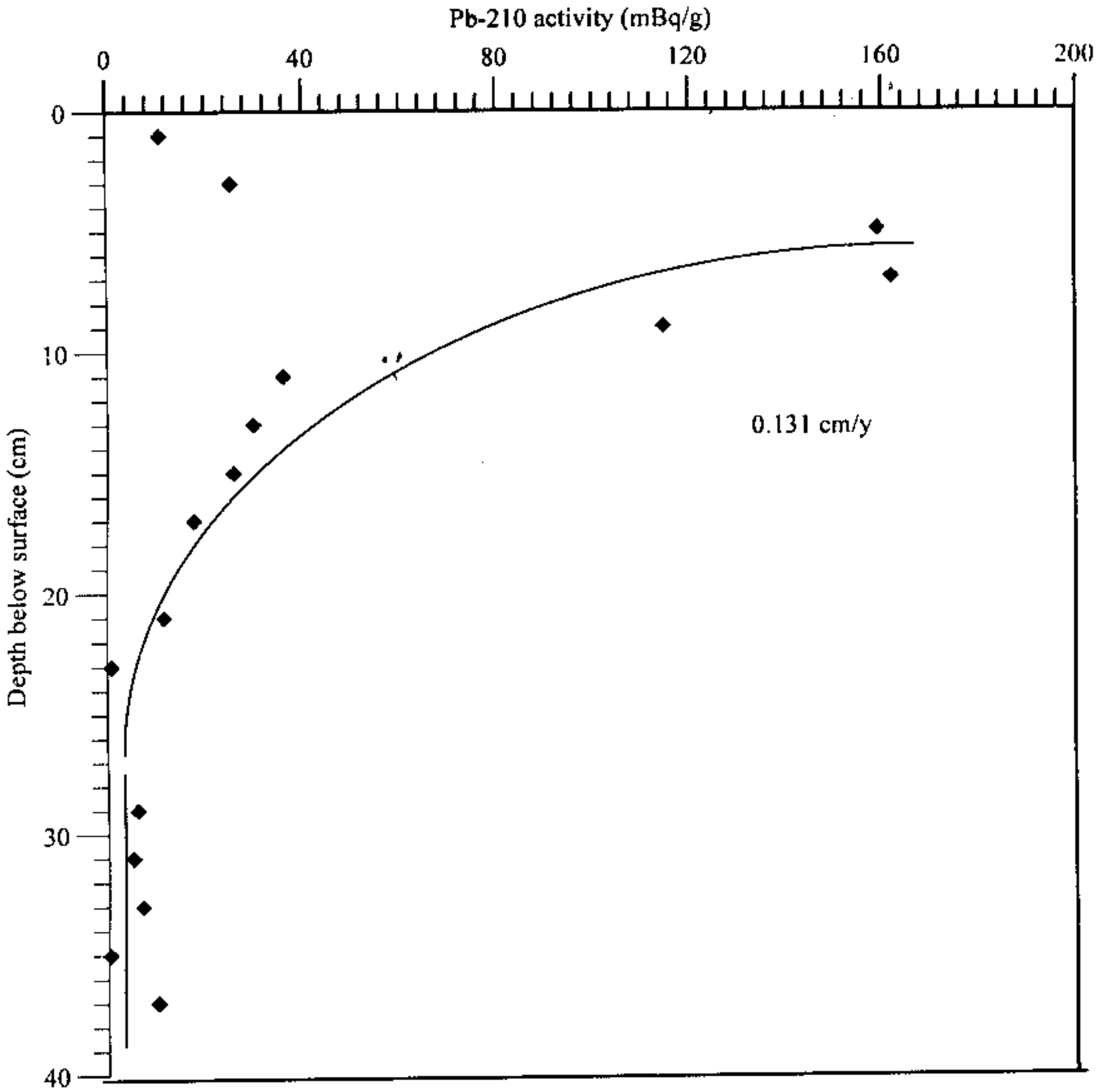


FIG. 22: ^{210}Pb ACTIVITY IN SEDIMRNT CORE D7 (LOCATION NEAR NEHRU PARK, GAGRIBAL SUB-BASIN)

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