EVALUATION OF RECENT TRENDS OF SEDIMENTATION IN INDIAN LAKES USING ^{210}PB AND ^{137}CS DATING TECHNIQUES

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ABSTRACT

In the present study, ^{210}Pb and ^{137}Cs dating techniques have been employed to determine the recent sedimentation rates in Nainital, Bhimtal, Sat-tal, Naukuchiyatal lakes of Uttaranchal, Mansar and Dal-Nagin lakes of Jammu and Kashmir, Sagar and Bhopal lake of Madhya Pradesh and Barapani reservoir (artificial lake) of Meghalaya. These lakes mainly represent western Himalayas, Central India and north-east Himalaya.

The weighted mean of sedimentation rates i.e., 1.44 ± 0.18 cm/y in Bhimtal lake, 0.74 ± 0.04 cm/y in Naukuchiyatal lake, 0.84 ± 0.05 cm/y in Sat-tal lake, 0.80 ± 0.05 in Nainital lake, and 0.23 ± 0.03 cm/yr in Mansar lake have been observed. The average rate of sedimentation in Dal lake was 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 was 0.41 ± 0.05 cm/y since 1964 marginally reduced to 0.34 ± 0.03 cm/y since 1987. The rate of sedimentation showed two types of sedimentation pattern in the Barapani reservoir located in north-east Himalaya: One part of the reservoir receiving the sediment at higher rate, weighted mean 1.76 ± 0.16 cm/y while the other part comparatively at lower rate of 0.72 ± 0.16 cm/y (weighted mean). In Sagar lake, the sedimentation rate was found between 0.14± 0.02 to 1.68± 0.18 cm/y (weighted mean 0.58 ± 0.02 cm/y) in different parts of lake. The average rate of sedimentation in upper Bhopal lake stands 0.97± 0.16 cm/yr.

INTRODUCTION

A large number of natural lakes occurring in the country are famous for their picturesque view and most of them are being used for drinking and irrigation purposes like Nainital, Dal_Nagin, Sagar and Bhopal lakes are main source of drinking water supply to Nainital, Srinagar, Sagar and Bhopal cities respectively. These lakes are important in maintaining the hydrological, ecological and environmental balance of the region. However, the increasing anthropogenic activities in recent years have greatly affected the hydrological regime of the lakes in the country and inflow of eroded material and other contaminant from the lake catchment have accelerated eutrophication process and rate of sedimentation (Ishaq and Kaul, 1988: Zutshi, 1985, Bhishm Kumar et al., 1999). This higher rate of sedimentation has diminished the useful life of several small lakes within the country and others are shrinking at alarming rate due to accelerated sedimentation. Therefore, it is a matter of great concern to the authorities to know the accurate sedimentation rates and causes of higher rate of sedimentation in order to take necessary measures to save the lakes from diminishing. Physicochemical and biological characteristics of lakes in India have been studied in detail but very limited efforts have been made to estimate sedimentation rates in lakes using advanced techniques. The rate of sedimentation can be estimated using conventional methods like lake sounding method, sediment balance method and advanced techniques like, remote sensing and isotopic techniques. However, in case of remote sensing technique, the information is obtained on an aggregate level while one can estimate sedimentation rate in different parts of a water body using radiometric dating techniques. Although several radioisotopes are useful in geochronological studies of lake sediments, but ^{210}Pb and ^{137} Cs have been used widely in the developed countries and provide accurate estimation of sedimentation rate. In the present study, environmental radioisotopes Caesium -137 (^{137}Cs) and geogenic radioisotope Lead -210 (^{210}Pb) have been used for radiometric dating techniques of lake sediment. Thus sedimentation rates have been estimated in various lakes such as Nainital, Bhimtal, Naukchiatal, Sattal, Da_Naginl, Mansar, Sagar, Bhopal and Barapani (artificial lake/ reservoir) using ^{137}Cs and ^{210}Pb dating techniques.

STUDY AREA

The Nainital, Bhimtal, Naukchiatal and Sattal in Uttaranchal, Dal_Nagin and Mansar in Jammu and Kashmir, Sagar and Bhopal in Madhaya Pradesh and Barapani reservoir (artificial lake) in Meghalaya having different geomorphological, geological and climatic conditions were selected to estimate the rate and pattern of sedimentation. The morphometric features of the lakes are presented in the table 1.

The Bhimtal, Naukuchiatal and Sattal lakes, popularly known as the "Lake Region of Bhimtal", are located in close proximity of Nainital Lake. Physiographically, these lakes are in the southern fringe of the Lesser Himalayas in Kumaun region of Uttaranchal. The Nainital hills encompass a rock succession that includes granites and the sediments and have thrusted over Siwaliks along the Main Boundary Thrust (MBT). The MBT is tectonically very active and is manifested in large scale hillside instability in the region (Valdiya, 1988). The lithology around Nainital consists of carbonate rocks, calcareous slates, argillaceous limestones, ferrugious shales, algal dolomites, black shales with marlite, greywacke, siltstones etc. The Bhimtal is comprised of metabasites associated with shallow water quartzites, grits, conglomerates and phyllites. Naukchiatal lake is surrounded by metavolcanics and wuartzites, whereas Sattal lake is developed in quartizitic country. Among all the Kumaun lakes, the Nainital is one of the major tourist places of Uttaranchal. Since the 1980s, increased local population pressure and tourist traffic resulted in a sudden spurt in construction activity and unplanned development of infrastructural facilities at Nainital to cater to the demands of the tourist as well as the local population. This has resulted in rapid degradation of the lake and its environment.

The Dal-Nagin lake is located in the Lesser Himalayan region of Kashmir Valley. The Dal lake is one of the most attractive fresh water lakes of India. . Although the lake comprises of several sub-basins and myriads of inter-connecting channels, but practically it is divided only in 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

Table 1. Geomorphological features of the Western Himalayan lakes

Feature	Name of the Lake								
	Bhopal	**Sagar**	**Bhimtal**	**Nainital**	**Naukuchiatal**	**Sattal**	**Barapani**	**Dal**	**Mansar**
Height amsl. (m)	508.65	517	1340	1937	1300	1280	1200	1583	666
Latitude	$23^0$10' N	$23^0$50' N	$29^0$21' N	$29^0$24' N	$29^0$25'N	$29^0$21'N	$25^0$28'N	34^0N	$32^0$40' N
Longitude	77^0 15' E	78^0 45' E	79^0 24'E	79^0 28'E	$79^0$20'E	79^0 32' E	$91^0$42' E	75^0E	75^0 5' E
Surface Area (km^2)	30.72	1.45	0.478	0.46	0.306	0.249	9.6	13.39	0.59
Max. Length (m)	10600	1247	1974	1400	1050	1300	5800	9117	1204
Max. Width (m)	37500	1207	457	450	675	190	1800	3588	645
Mean Depth (m)	4.0	2.69	11.5	16.2	21.89	8	17.3	0.80	21
Max Depth (m)	9.39	5.3	25.8	27.3	42.25	20	54	4.07	38.25
Total Vol. (Mm^3)	102	3.89	4.61	8.58	7.37	0.89	16.69	12.61	12.37
Catchment Area (km^2)	372	18.17	10.77	4.7	3.25	5.69	217.4	337.17	1.67
Av. Rainfall (mm)	1200	1196	2143	2488	2424	1500	2400	869	1500
SummerAir Temp (^{0}C)	32	31	32	20	31	32	25	22	32
Winter Av. Temp. (^{0}C)	19	1	11	5	11	20	5	3	10
Shape of Lake	Not well Defined	Not well Defined	'C' Type	Crescent shape	'B' Type	'S' Type	P Type	Not well Defined	Oval

India. This famous lake is shrinking and of late, is getting severely polluted by the swelling human settlements within it and on its periphery. In the twelfth century AD, it had an area of about 75 sq. km. Since then it has been continually shrinking and has been reduced in terms of its open water area coverage to about 8 sq.km i.e., it has lost its aerial dimension by about 90% since 1200 AD.

In Siwalik Himalaya of Jammu region, there are two prominent lakes, namely Mansar and Surinsar, located in the east of the Jammu city. These lakes are 16 km apart in Siwalik Himalaya. Mansar lake is comparatively larger than the Surinsar lake. 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. It is famous also for its religious importance. In order to develop tourism, large number of construction activities has taken place in the lake catchment. It has been felt that the Mansar lake is shrinking due to higher rate of sedimentation.

The Upper Bhopal Lake, the largest fresh water lake in M.P., India, is located in the heart of Bhopal town. In spite of several ecological problems associated with the upper Bhopal lake, it has pride to be the largest fresh water in Central India and has been included in the Ramasar convention for wetland. The lake was formed by constructing an earthen dam on the river Kolans by Raja Bhoj about 1100 years ago to provide drinking water to his subjects and to create an aesthetic environment. Therefore, the upstream portion of the lake is shallow in comparaision to the downstream portion of the lake. It is a typical urban lake, mainly used for providing drinking water for the mammoth population of old city of Bhopal. The Upper Bhopal Lake is the most important tourist recreation center. Fisheries are also of very important concern in the lake water.

Sagar lake is situated in the middle of Sagar City in M.P. in the Vindhyan terrain of Bundelkhand region. The lake is is divided into two parts, the main lake and small lake. There are a number of small inflowing channels into the lake carrying city waste water. The lake receives fresh water from the precipitation over the lake basin area, which flows into the lake through overland flow. During the rainy season, when water level rises in the lake, overflow from the lake takes place through Mogha weir only. The lake is two hundred years old. Historical records assign an artificial origin whereas geological evidences are in favour of natural origin of this lake (Mishra, S.K., 1969). Geological evidences also say that originally the lake had an area of 580 hectares as against the present 145 hectares and the maximum depth was about 60 feet against the present depth of about 16 feet (Yatheesh, 1990). The lake is having a drainage pattern, i.e., north-west ward, in concordant with that of the district (Krishnan, 1967). The landuse pattern of the basin is 40.9 % barren land, 20.9 % agriculture, 18.7 % settlement, 11.5 % open forest and 8.1 % water body.

The Barapani reservoir located on river Wah Umiam was created by constructing a concrete dam near Barapani village 16 km ahead of Shillong on Guwahati - Shillong road. The length of the concrete dam is 195 m, main earth dam is 37.2 m and a road dyke is 17.4 m. The reservoir and its entire catchment are located in the East Khasi Hills districts of Meghalaya in the north eastern part of India. The project is a Hydroelectric project meant for generation of power with installed capacity of 4x9000 KW. The landuse in the catchment can be divided mainly in three classes i.e., reserve forest (11%), unclassified forest- cultivated land, miscellaneous tree crops and orchards (71.5%) and Grazing land- pasture, fallow and waste land (17.5%) respectively. Shifting cultivation and stream bank cutting are the major problem of the region, although deforestation due to other causes and gully erosion are also important problems of the area. Studies conducted on micro watershed have revealed that, development of new sites for building construction, road side erosion and kitchen gardening are some of the major source of silt production.

METHODOLOGY

In order to estimate the sedimentation rates in lakes, sediment cores were collected with a gravity corer from different parts of the lakes (Table 2). The length of collected cores ranged from 30 to 64 cm. The collected cores were sliced into segments at 2 cm intervals for analytical work. Bulk density was determined before drying the samples in an oven at 105 ^{0}C temperature for about 24 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 along with the percent of organic matter was determined. In order to determine 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 locations of lakes are shown in Fig. 1.

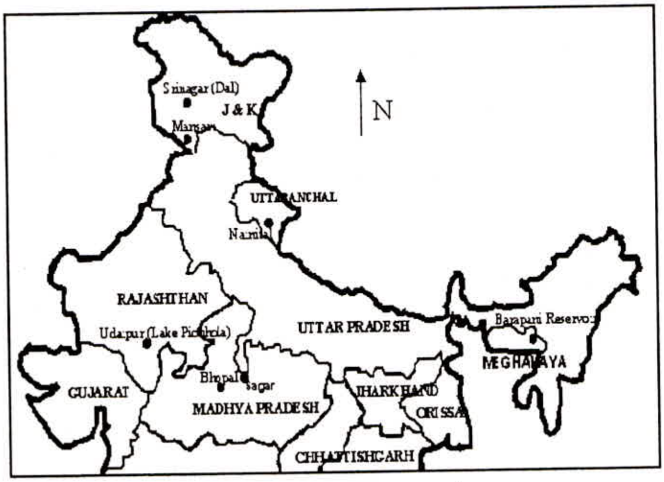

Fig. 1. Location map of the lakes

For measurement of ^{210}Pb, the basic radiochemical procedure involves adding of ^{209}Po as a yield tracer, leaching the sediment samples with aqlua regia, the residual solids were filtered off and the solution was dried and converted to chloride with concentrated HCI. The final solution was taken in 0.5 N HCI. Polonium (Po-210) nuclides were then spontaneously deposited on silver planchettes by adding ascorbic acid in the HCI solution prior to alpha counting using Si surface barrier detectors connected to a multi-channel analyzer. 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.

Table 2. Details of the sediment cores collected from the different lakes.

Lakes/ Reservoirs	Number of Core Collected	Core Analysed using ^{137}Cs and ^{210}Pb dating techniques	
		^{137}Cs	^{210}Pb
Nainital	3	3	3
Bhimtal	4	4	3
Naukchiatal	3	3	
Sattal	4	4	2
Dal	14 cores	14	3
Mansar	5	5	2
Sagar	12	11	5
Bhopal	10	6	4
Barapani Reservoir	11	9	4

A number of models, such as Constant Rate Supply (CRS) or Constant Flux (CF) and Constant Initial Concentration (CIC), 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, CRS model has been used for estimating rates of sedimentation.

The ^{137}Cs activity in each segment was determined by gamma counting of the oven-dried samples using Hyper Pure Germanium detector coupled with a 4096-channel multi-channel analyzer (MCA). A ^{137}Cs standard, having essentially the same geometry and density was used. About 10 gm of the sliced cores was used to measure ^{137}Cs activity for about 7200 to 28800 s to obtain good statistical accuracy. The detection limit of MCA for ^{137} Cs was 0.25 mBq/g and the standard counting error was less than 10% in the core sections.

RATE OF SEDIMENTATION

The ^{137}Cs profile closely parallels its weapon fall-out record pattern as reported by earlier investigators (McHenry et al., 1973, Livingston and Cambray, 1978) i. e., an initial appearance in 1952-1953, a subsidiary peak in 1957-1958 and a major peak in 1963-1964. Using depths recorded in 1963-1964 as the datum levels, the average sedimentation rate of different lakes have been computed (table)

Nainital Lake

The three sediment cores collected from the north and south sub-basins were selected for ^{137}Cs activity measurement in order to cover the whole lake. About 150 samples, belonging to three sediment cores were analysed at Bhabha Atomic Research Centre (BARC), Mumbai, India, for ^{210}Pb and ^{137}Cs activities. Saravanakumar et al. (1997) have discussed in details about the measurements of ^{210}Pb and ^{137}Cs activity and models used including assumptions made in the interpretation of ^{210}Pb. The standard counting error in case of ^{210}Pb method was generally less than 10% in the upper sections of the cores and slightly higher at the deeper sections. In case of ^{137} Cs, the standard counting error was less than 10% in the core sections.

The sedimentation rate obtained by ^{210}Pb in different parts of the lake varies from 0.48 cm/yr to 1.24 cm/yr. In case of ^{137}Cs, it varies between 0.60 cm/yr and 1.35 cm/yr. The sedimentation rate is higher in the intermediate portions located just adjacent to the bank zones while comparatively moderate (0.64 cm/yr) in steeper bank zones. The deeper portions away from the bank of the lake, receive sediment at lower rate (0.48 cm/yr). The average sedimentation rate is 0.75 cm/yr. The area weighted average rate of sediment accumulation in Nainital lake is 3715 $\pm$ 400 m^3/yr.

Bhimtal Lake

Four cores (namely B1, B2, B3 and B4) were subjected to the ^{137}Cs and three cores (B1, B2, and B3) were analysed for ^{210}Pb activity. From the results, it is seen that the 1963 peaks of ^{137}Cs are not clearly identifiable in B1, B2 and B3. However, Core B4 exhibits a better ^{137}Cs activity pattern that corresponds to the profiles obtained in Lake Nainital. Since, the 1963 peak occurs at a depth of about 35cm below mud-water interface, the rate of sedimentation is estimated as 0.90 cm/y. For the cores B1, B2, and B3, the ^{210}Pb technique has been applied and the rate of sedimentation obtained from the slope of the ^{210}Pb activity – depth curve are 2.29 cm/y, 1.74 cm/y and 3.87 cm/y respectively. If these rates are used to back-calculate the probable depth of sediment deposited during 1963, then it is seen that the insufficient core length has rendered the application of ^{137}Cs method inapplicable in these three cases.

The core B1 was collected from the deepest part of the lake probably towards which the sediment flow from all directions and hence the rate of sedimentation is comparatively higher. The core B3 shows the highest rate of sedimentation due to its location at the debouching point of the major inflow drain. As per the lake bathymetry, location of core B4 is on a moderately steep slope of the lake, therefore the sedimentation rate near B4 should be lower and it is also confirmed by radiometric dating of the sediment core. The area weighted average rate of sediment accumulation in Bhimtal lake is about 6859 $\pm$ 800 m^3/y. This is equivalent to the surface area normalized rate of sedimentation of about 1.44 cm/y (Bhishm Kumar and Rm. P. Nachiappan, 2003).

Naukuchiatal Lake

Three cores (namely NKN, NKC and NKE) were subjected to ^{137}Cs analysis. From the results, it is seen that the 1963 peak of Cs-137 is clearly identifiable and corresponds to a depth of 23, 15 and 37 cm below the mud-water interface in cores, NKN, NKC and NKE respectively. The highest rate of sedimentation of 0.95 cm/y is observed in the eastern part of the lake closer to the debauching point of a major inflow stream. In the northern part of the lake, the rate of sedimentation is about 0.59 cm/y and at the central portion, as may be expected in a conical trough shaped lake, the rate of sedimentation is lower and is about 0.38 cm/y. Therefore, it appears that the distribution of sedimentation rate in Naukuchiatal is similar to that observed in Nainital lake in the Kumaun region (NIH, 1999). The area weighted average rate of sediment accumulation in Naukuchiyatal Lake is about 2271$\pm$ 71 m^3/y. This is equivalent to the surface area normalized mean rate of sedimentation of about 0.74 cm/y (Bhishm Kumar and Rm. P. Nachiappan, 2003).

Sat-tal Lake

The ^{137}Cs activity was analysed in three selected cores (S1, S2, S3 and S4) at NIH, Roorkee. The 1963 peak of ^{137}Cs is not clearly identifiable in S2, S3 and S4. However, Core S1 exhibits a better ^{137}Cs activity pattern that corresponds to the profiles obtained in lakes Naukuchiyatal and Nainital. Since, the 1963 peak occurs at a depth of about 21cm below mum-water interface, the rate of sedimentation is estimated as 0.54 cm/y. For the cores S3 and S4, the ^{210}Pb technique has been applied and the rate of sedimentation obtained from the slope of the ^{210}Pb activity – depth curve are 1.55 cm/y, and 1.26 cm/y for S3 and S4 respectively. Due to shortage in analytical time ^{210}Pb separation and radiometric analysis of samples from core S2 could not be completed. If the available rates of sedimentation are used to back-calculate the probable depth of sediment deposited during 1963, then it is seen that the insufficient core length has rendered the application of ^{137}Cs method inapplicable in the case of Core S3 and S4. The accumulation rate in the three locations S1, S3 and S4 are 0.54 cm/y, 1.55 cm/y and 1.26 cm/y respectively. The weighted average rate of sediment accumulation rate in Sat-tal lake is about 1499 ± 58m3/y. This is equivalent to the surface are normalized rate of sedimentation of about 0.84 cm/y (Bhishm Kumar and Rm. P. Nachiappan, 2003).

Dal-Nagin Lake

About 355 samples, belonging to the 14 sediment cores were analysed for ^{137}Cs while about 150 samples were subjected to various chemical treatments and then radiometric dating of ^{210}Pb. The current sedimentation rate after 1986-87 obtained by ^{137}Cs in Hazratbal basin varies from 1.25 to 0.08 cm/yr (from 1.16 to 0.6 cm/yr after 1963-64), in Nagin basin from 0.91 to 0.08 cm/yr (from 1.0 cm/yr to 0.20 cm/yr after 1963-64), in Bod Dal basin from 0.25 to 0.06 cm/yr (from 0.4 to 0.26 cm/yr after 1963-64), and in Gagribal basin from 0.25 to 0.14 cm/yr (from 0.23 to 0.14 cm/yr). In case of ^{210}Pb, it is 0.21 cm/yr for Nagin basin for sediment core D14 which is in excellent matching with the average sedimentation rate (0.20 cm/yr) estimated using ^{137}Cs dating technique. As the rates are very less therefore, the variation in sedimentation rate in the last 10-15 years is not reflected in ^{210}Pb measurements (Bhishm Kumar and Rm. P. Nachiappan, 2003).

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.

Mansar Lake

Rate of sedimentation determined using ^{137}Cs techniques of the 5 cores collected from different places were determined. At the two places A and E, the rate was 0.37 cm/yr, and at B 0.14 cm/yr and at D and E (two places) 0.20 cm/yr. The mean rate of sedimentation computed for the lake is 0.23 ± 0.02 cm/y. ^{210}Pb dating technique was used for the corsscheck of the results obtained using ^{137}Cs dating techniques at few sites. Keeping this in view, sedimentation rates have also been estimated at locations A, D and E using ^{210}Pb dating technique. These vary from 0.24 cm/y to 0.34 cm/y that are comparable with the rate estimated using ^{137}Cs dating technique.

Sagar Lake

To determine the sedimentation rate of lake, samples of eleven cores were analysed using ^{137}Cs and five cores were analysed using ^{210}Pb techniques. The sediment cores collected from different locations contain organic matter in the range of 14 to 27 %. The sedimentation rate in the lake varies from 0.14 cm/yr to 1.68 cm/yr with the mean sedimentation rate of 0.58 ±0.02 cm/yr. The higher rate of sedimentation is obsevred in the portion of the lake where it receives the inflow from Kanera canal and also at other pocket of lake where lake receives sediment due to erosion from upland areas.

Barapani Reservoir/Artificial lake

Total 11 cores were collected from the Barapani Reservoir out of which 9 cores were analysed for ^{137}Cs activity and 4 cores were analysed for ^{210}Pb activity. The rate of sedimentation showed two types of sedimentation pattern in the Barapani reservoir located in north-east Himalaya. One part of the reservoir receives sediment at higher rate i.e., 1.62 to 1.92 cm/y (weighted mean 1.76 ± 0.16 cm/y) awhile in the other part of the reservoir, sedimentation rate varies between 0.46 and 1.00 cm/y (weighted mean 1.76 ± 0.16 cm/y). Results reveals that the rate of sedimentation has been considerably increased after 1986. in one part of the lake. This might be due to the increased construction activities and excavation work including the increase in agricultural activities in the catchment (Bhishm Kumar et al 2001).

Bhopal Lake

Six sediment cores were analysed for ^{137}Cs and four cores for ^{210}Pb activity to cross check the results of the ^{137}Cs. The sedimentation rate varies from 0.14 cm/yr to 2.16 cm/yr with the average sedimentation rate of 0.97 cm/yr The sedimentation rate obtained using ^{137}Cs is comparable well with the rate determined by ^{210}Pb. The results reveals that the rate of sedimentation in the upstream portion of Upper Bhopal Lake is higher as a result of silt load entering into the through the Kolans stream. The rate of sedimentation decreases from the upper part to the lower part of the lake.

CONCLUSIONS

The average rate of sedimentation of the Himalayan lakes in increasing order are found to be 0.23 ± 0.03 cm/yr (about 1347 m^3/y) in the Mansar, 0.74 ± 0.04 cm/y (2271 m^3/y) Naukuchiyatal, 0.80 ± 0.05 cm/yr (156563 m^3/y) in Dal, 0.80 cm/yr (3967 m^3/y) in Nainital, 0.84 cm/y (2092 m^3/y) Sat-tal, 1.44 cm/y (6859 m^3/y) in Bhimtal lakes. The sedimentation rate in the Bhopal lake is found 0.97 cm/y (2979840 m^3/y) while in Sagar lake, it is 0.58 ±0.02 cm/yr (84100 m^3/y). The Barapani reservoir indicated two rates of sedimentation i.e. 1.76 ± 0.16 cm/y in the lower part and 0.72 ± 0.16 in the upper part.

The results reveal that the maximum rate of sedimentation is found near the entrance of main drain of the lake catchment and minimum rate in the middle zone of the lake. The variation in sedimentation rate within the lake depend upon the inflow from the different parts of the lake.

The study reveals that ^{210}Pb geochronological dating is very useful to determine recent sediment accumulation rates and pattern in lakes where the application of other techniques are very difficult due to tough terrain in Himalayan region and smaller surface area of lakes. ^{137}Cs dating techniques appears a powerful tool for determining the sedimentation rate and pattern.

The average rate of sedimentation seems not very high, but it hans been obsereved that certain parts of every lake is getting filled comparatively at a higher rate of sedimentation. Therefore, there is a need to take necessary precautions to check the entry of sediments into the lake by putting some suitable barriers at the inflow points and then regular removal of the sediment deposited at the barrirer sites.

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