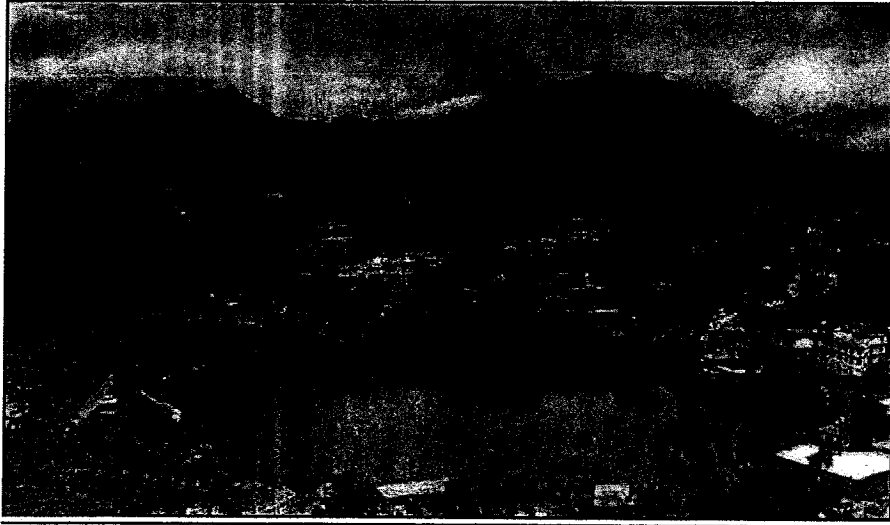


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**Draft Final Report**

# **STATUS REPORT ON RAWALSAR LAKE, MANDI HIMACHAL PRADESH**



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395

2

## TABLE OF CONTENTS

SN	Content	Page No.
<b>1.0</b>	<b>INTRODUCTION</b>	4
1.1	General	4
1.2	Lake Sedimentation	4
1.3	Isotopic Characteristics	5
1.4	Water Quality	6
1.5	Importance of the study	8
1.6	Objectives	8
<b>2.0</b>	<b>REVIEW OF LITERATURE</b>	9
<b>3.0</b>	<b>STUDY AREA</b>	11
<b>4.0</b>	<b>DATA AND METHODOLOGY</b>	12
4.1	Determination of lake sedimentation rate using $^{137}\text{Cs}$	12
4.1.1	General	12
4.1.2	Sediment sample collection	13
4.1.3	Processing of Sediment Samples	15
4.1.4	Measurement of $^{137}\text{Cs}$ (cesium-137) activity	16
4.1.5	Estimation of $^{137}\text{Cs}$ activity	18
4.2	Isotopic Characterization of the Lake	18
4.2.1	Sampling and isotopic analysis	19
4.3	Water Quality Analysis	20
<b>5.0</b>	<b>RESULTS AND DISCUSSION</b>	21
5.1	Land use and land cover	21
5.2	Estimation of rate of sedimentation	22
5.3	Isotopic Characterization of the Lake	25
5.3.1	Lake-Groundwater Interaction	26
5.4	Water Quality	26
<b>6.0</b>	<b>CONCLUDING REMARKS</b>	30

## LIST OF FIGURES

<b>Figure No.</b>	<b>Title</b>	<b>Page No.</b>
Fig.1:	View of the Rewalsar lake, Mandi	12
Fig. 2:	Google Earth view of Rewalsar lake	12
Fig. 3:	Sediment core collection from Rewalsar Lake	13
Fig 4:	Core sampler for sediment analysis	14
Fig 5:	Sample Preservation	14
Fig 6:	Sample Processing (crushing and grinding)	16
Fig. 7:	Multichannel Gamma spectrometer used for radiometric dating Technique	17
Fig. 8:	Germanium Detector	17
Fig. 9:	Lake water sampling for isotopic analysis	19
Fig 10:	Location of sampling sited for isotopic analysis	19
Fig. 11.1:	CFIRMS at NIH	20
Fig. 11.2:	DIIRMS at NIH	20
Fig. 12:	Location of water quality sampling sites of the lake	20
Fig. 13:	Water quality sampling of Rewalsar lake	21
Fig. 14:	Measurement of sechchi depth data of the lake	21
Fig. 15:	Land use and land cover map of the Rewalsar lake catchment	22
Fig. 16:	Statistic of land use and land cover of Rewalsar lake catchment	22
Fig. 17:	Spectrum obtained after analysis of sample	23
Fig.. 18:	Activity plot for samples in the sediment core	24
Fig. 19:	Graph of $\delta^{18}\text{O}$ versus $\delta\text{D}$ Rewalsar Lake	25
Fig. 20:	Feeding of fish at the lake	29

## LIST OF FIGURES

<b>Table No.</b>	<b>Title</b>	<b>Page No.</b>
Table 1:	Stable isotopes and reference standards used for ratio measurements	6
Table 2:	Water quality standards by CPCB	7
Table 3:	Water quality Standards as per BIS	7
Table 4:	Water quality of Rewalsar Lake during April, 2009	10
Table 5:	Water quality of Rewalsar Lake during July, 2009	11
Table 6:	$^{137}\text{Cs}$ activity in different samples	23
Table 7:	Isotopic characteristics of Rewalsar Lake and surrounding ground water	25
Table 8:	Results of water quality analysis for monsoon season	27
Table 9:	Results of water quality analysis for winter season	27
Table 10:	Variation in water quality parameters during June, 2016	28
Table 11:	Concentration of heavy metals (mg/l) in Rewalsar Lake	28
Table 12:	Bacteriological characteristics of the lake	29
Table 13:	Sechchi disc depth data for the lake	29

## 1.0 INTRODUCTION

### 1.1 General

Lakes are inland bodies of water that lack any direct exchange with an ocean. Lake ecosystems are made up of the physical, chemical and biological properties contained within these water bodies. Lakes may contain fresh or salt water (in arid regions). They may be shallow or deep, permanent or temporary. Lakes of all types share many ecological and biogeochemical processes and their study falls within the discipline of 'limnology'. Lakes are dynamic ecosystems involving interactions among biological, chemical and physical processes which are frequently either quantitatively or qualitatively distinct from those on land or in air. Because the boundaries between water and land, and water and air are distinct, there is tight coupling among many ecosystem components. Many organisms depend on freshwater for survival, and humans frequently depend on lakes for a great many 'goods and services' such as drinking water, waste removal, fisheries, agricultural irrigation, industrial activity, and recreation. For these reasons lakes are important ecosystems. Lake ecosystems are influenced by their watersheds, the geological, chemical and biological processes that occur on the land and streams that lie uphill. The movement of chemicals, sediments, detritus, and of many organisms, is typically unidirectional from the watershed to the lake, but fish may migrate upstream, and aquatic insects may emerge and disperse on to land. A lake and its watershed are often considered to be a single ecosystem. Understanding a lake's physical, chemical, and biological properties is essential to determining the lake's condition and in making informed lake management decisions. These include physical measurements such as water clarity, dissolved oxygen, temperature etc., chemical measurements such as nutrients, suspended solids, pH, conductivity etc and biological measurement such as coliform bacteria, DO, BOD etc.

### 1.2 Lake Sedimentation

Nonpoint source pollutants come from a number of sources and are washed into our waterways by surface runoff. When land disturbing activities occur, soil particles are transported by surface water movement. Soil particles transported by water are often deposited in streams, lakes, and wetlands. This soil material is called sediment. Sediment is the loose sand, clay, silt and other soil particles that settle at the bottom of a body of water. Sediment can come from soil erosion or from the decomposition of plants and animals. Land disturbing activities such as road construction and maintenance, timber harvesting, mining, agriculture, residential and commercial development, all contribute to this problem. Wind, water and ice help carry these particles to rivers, lakes and streams.

Sedimentation is the processes by which suspended material gets settled in the water bodies by gravity. Suspended material may be particles, such as clay or silts, originally present in the source water. Suspended material or floc is typically created from materials in the water and chemicals used in coagulation or, in other treatment processes, such as lime softening (see Lime Softening chapter). Sedimentation is accomplished by decreasing the velocity of the water to a point which the particles will

no longer remain in suspension. When the velocity no longer supports the particles, gravity will remove them from the water flow.

There are various techniques for the determination of the rate of sedimentation in lake/reservoirs, such as range line method, contour method, sediment balance method, remote sensing techniques and radiometric dating techniques. Several environmental isotopes including  $^{210}\text{Pb}$ ,  $^{137}\text{Cs}$  and  $^{14}\text{C}$  find applications in the estimation of rate of sedimentation in lakes. However,  $^{14}\text{C}$  is more useful for paleo-hydrological studies. Artificial radio-isotopes used for sediment accumulation studies include  $^{239}\text{Pu}$ ,  $^{240}\text{Pu}$  and  $^{241}\text{Am}$ . However, for the dating of recent sediments,  $^{210}\text{Pb}$  (100 to 150 years BP) and  $^{137}\text{Cs}$  (post 1954) are widely used. In the present study radiometric dating technique has been used.

### 1.3 Isotopic Characteristics

Isotopes are the atoms of an element having same atomic number (Z) but different atomic weight (A). For example, hydrogen has three isotopes having the same atomic number of 1 but different atomic masses or weights of 1, 2 and 3 respectively i.e.,

- $^1_1\text{H}_0$  - Only one proton in nucleus and one electron revolving around the nucleus in an orbit.
- $^2_1\text{H}_1$  - One neutron added to the nucleus of  $^1_1\text{H}_0$  atom.
- $^3_1\text{H}_2$  - One more neutron added to the nucleus of  $^2_1\text{H}_1$ .

Similarly, oxygen has eleven isotopes,  $^{12}\text{O}$ ,  $^{13}\text{O}$ ,  $^{14}\text{O}$ ,  $^{15}\text{O}$ ,  $^{16}\text{O}$ ,  $^{17}\text{O}$ ,  $^{18}\text{O}$ ,  $^{19}\text{O}$ ,  $^{20}\text{O}$ ,  $^{21}\text{O}$  and  $^{22}\text{O}$ , but except  $^{16}\text{O}$ ,  $^{17}\text{O}$ , and  $^{18}\text{O}$  all other isotopes are radioactive and their existence in nature is very small (half life vary from 150 seconds to few femo seconds - of the order  $10^{-15}$  seconds). Therefore, we normally talk about only three isotopes of oxygen i.e.,  $^{16}\text{O}$ ,  $^{17}\text{O}$ , and  $^{18}\text{O}$ . The carbon also has three isotopes  $^{12}\text{C}$ ,  $^{13}\text{C}$  and  $^{14}\text{C}$ .

Isotopes can be classified in two important categories, (i) stable isotopes and (ii) unstable isotopes. Stable isotopes are the atoms of an element, which are satisfied with the present arrangement of proton, neutron and electron. On the other hand, unstable isotopes are the atoms of an element which do not satisfy with the present arrangement of atomic particles and disintegrate by giving out alpha ( $\alpha$ ), beta ( $\beta$ ) particles and/or gamma ( $\gamma$ ) radiation etc. and transform into an another type of atom. This process continues till the stable nuclide (element) is formed. Because of disintegration or the property of giving out radiation, the unstable isotopes are also called radioactive isotopes. For example,  $^1\text{H}$  and  $^2\text{H}$  are stable isotopes while  $^3\text{H}$  is unstable. Similarly  $^{12}\text{C}$  and  $^{13}\text{C}$  are stable isotopes while  $^{14}\text{C}$  is unstable. On the other hand, isotopes of oxygen ( $^{16}\text{O}$ ,  $^{17}\text{O}$  and  $^{18}\text{O}$ ) are stable.

Another category of isotopes has been devised that is called environmental isotopes. These isotopes have different types of categories i.e. naturally occurring stable and radioactive isotopes and radioisotopes introduced into the atmosphere due to anthropogenic activities etc. The environmental radioisotopes whether naturally occurring due to cosmic ray interaction with various gaseous molecules or anthropogenically produced and become the part of hydrological cycle are safe in normal conditions and do not pose any threat to human health.

**Table 1: Stable isotopes and reference standards used for ratio measurements**

Isotope	Ratio	% natural Abundance	Reference (abundance ratio)	Commonly measured phases
$^2\text{H}$	$^2\text{H}/^1\text{H}$	0.015	VSMOW ( $1.5575 \cdot 10^{-4}$ )	$\text{H}_2\text{O}$ , $\text{CH}_2\text{O}$ , $\text{CH}_4$ , $\text{H}_2$ , OH <sup>-</sup> minerals
$^{15}\text{N}$	$^{15}\text{N}/^{14}\text{N}$	0.366	AIR $\text{N}_2$ ( $3.677 \cdot 10^{-3}$ )	$\text{N}_2$ , $\text{NH}_4^+$ , $\text{NO}_3^-$ , N- organics
$^{18}\text{O}$	$^{18}\text{O}/^{16}\text{O}$	0.204	VSMOW ( $2.0052 \cdot 10^{-3}$ )	$\text{H}_2\text{O}$ , $\text{CH}_2\text{O}$ , $\text{CO}_2$ , sulphates
VPDB ( $2.0672 \cdot 10^{-3}$ )			$\text{NO}_3^-$ , carbonates, silicates	OH <sup>-</sup> minerals

#### 1.4 Water Quality

Water quality is a general term that refers to a general description about the properties of a water body. Water quality is commonly assessed through the use of many different parameters. However, the importance of the various parameters depends on the use of the water. The term water quality therefore, must be considered relative to the use of water. In other words, the term 'water quality' can be defined as "physical, chemical and biological characteristics of water by which the user evaluates the acceptability of water". Lakes having high water quality possess properties that make it a high valued resource to society and nature. Declining or low water quality impacts the value of lakes – economically, ecologically, and socially. For example, if pollution enters a lake, it can reduce the water quality enough, such that it is unsafe to drink as well as harm organisms that live in the water, reducing the ecological value of the lake. These changes can alter perceived value of the water body and hence, reduce recreational activity and nearby land values. Water quality also determines the state of aquatic environments. Study of water quality is important for determining both human impacts and natural processes in the environment. For each parameter of water, the quality is generally reported with reference to a specific standard so as to make the qualitative assessment of the status of the water. The standards are set by governing organizations. In India the CPCB and BIS have set certain standards for different uses of water (Tables 12.1, 12.2).

**Table 2: Water quality standards by CPCB**

Designated Best Use	Class	Primary Water Quality Criteria
Drinking water source without conventional treatment but with chlorination	A	Total coliform organisms (MPN/100 ml) shall be 50 or less; pH between 6.5 and 8.5; Dissolved Oxygen 6 mg/L or more, and BOD 2 mg/L or less
Outdoor bathing (organized)	B	Total coliform organisms (MPN/100 ml) shall be 500 or less; pH between 6.5 and 8.5; Dissolved Oxygen 5 mg/L or more, and Biochemical Oxygen Demand 3 mg/L or less
Drinking water source with conventional treatment	C	Total coliform organisms (MPN/100 ml) shall be 5000 or less; pH between 6 and 9; Dissolved Oxygen 4 mg/L or more, and Biochemical Oxygen Demand 3 mg/L or less
Propagation of wildlife and fisheries	D	pH between 6.5 and 8.5; Dissolved Oxygen 4 mg/L or more, and Free ammonia (as N) 1.2 mg/L or less
Irrigation, industrial cooling and controlled disposal	E	pH between 6.0 and 8.5; EC less than 2250 micro mhos/cm, SAR less than 26, and Boron less than 2 mg/L

**Table 3: Water quality Standards as per BIS**

S. No.	Parameter and Unit	A	B	C	D	E
1	Taste	None	-	-	-	-
2	Odour	Un obj.	-	-	-	-
3	Colour (True)(Hazen Unit)	10	300	300	-	-
4	pH (max) (min:6.5)	8.5	8.5	8.5	8.5	8.5
5	Conductivity (25°C) uS/cm	-	-	-	1000	2250
6	DO (mg/l)(minimum)	6	5	4	4	-
7	BOD (3d, 27°C) (Mg/L)	2	3	3	-	-
8	Total Coliforms (MPN/100 ml)	50	500	5000	-	-
9	TDS (Mg/L)	500	-	1500	-	2100
10	Oil and Grease (Mg/L)	-	-	0.1	0.1	-
11	Mineral Oil (mg/L)	0.01	-	-	-	-
12	Total Hardness (Mg/L as CaCO <sub>3</sub> )	300	-	-	-	-
13	Chlorides (Mg/L as Cl)	250	-	600	-	600
14	Sulphates (Mg/L as SO <sub>4</sub> )	400	-	400	-	1000
15	Nitrates (Mg/L as NO <sub>3</sub> )	20	-	50	-	-
16	Free CO <sub>2</sub> (Mg/L)	-	-	-	6	-
17	Free NH <sub>3</sub> (Mg/L as N)	-	-	-	1.2	-
18	Fluorides (Mg/L as F)	1.5	1.5	1.5	-	-
19	Calcium (Mg/L)	80.10	-	-	-	-
20	Magnesium (Mg/L)	24.28	-	-	-	-
21	Copper (Mg/L)	1.5	-	1.5	-	-
22	Iron (Mg/L)	0.3	-	50	-	-
23	Manganese (Mg/L)	0.5	-	-	-	-

(Class A – Drinking water without conventional treatment but after disinfection. Class B – Water for outdoor bathing. Class C – Drinking water with conventional treatment followed by disinfection. Class D – Water for fish culture and wild life propagation. Class E – Water for irrigation, industrial cooling and controlled waste disposal)

Water quality can be degraded by a number of factors. One of the important causes is addition of nutrients to the water body which results into problems like eutrophication. At birth, lakes are deficient in nutrients and hence, are unable to support aquatic life. At this stage they are referred to as oligotrophic water bodies. With passage of time nutrients brought by sediments from the catchment get accumulated in them and their productivity increases. Through bacterial and other decompositions of the sediments, the water bodies become rich in nutrients on which phytoplankton thrive. With increase in phytoplankton and food supply, the zooplankton and other forms of animals also increase. Thus, with increase in species diversity and biological productivity, the water body passes from oligotrophic phase through the mesotrophic phase into the eutrophic phase. Eutrophication, thus, denotes the addition of nutrients and consequent increased productivity level of a water body. It describes the biological effects of an increase in concentration of plant nutrients, usually nitrogen and phosphorous (but sometimes others such as silicon, potassium, calcium, iron or manganese) on the aquatic ecosystem. It represents the natural aging process of the lake. However, human interference in the catchment changes the natural eutrophication dramatically through increased rates of nutrient input. This artificial eutrophication is called cultural eutrophication and, is the cause of concern for most lakes. Problems of aquatic weeds are reflection of this problem.

## **1.5 Importance of the study**

The Rewalsar Lake is significant from religious, cultural and tourism purposes. It is held as a sacred spot. However, water quality degradation has been reported for the lake. Due to pollution the nature of water has turned acidic (Tribune India, May 11, 2010). The poor sewerage system of Rewalsar town is further increasing the problem as contaminated water directly flows into the lake (Tribune India, May 11, 2010). According to the news published in the Tribune (May 14, 2014), more than 700 fish died during May 2014 at Rewalsar Lake. The death of fish is a regular feature of the lake but no systematic studies have been reported for the lake. The state Pollution Control Board analysed the the dissolved oxygen level in the lake in 2010 and it was found to be low. However, the causes of fish kills and other environmental issues of the lake have not been investigated so far. So, this study was proposed to review the environmental status of the lake, so that based on the environmental status further detailed investigations can be planned for the lake. .

## **1.6 Objectives**

The main objectives of the study are as follows:

- To determine the environmental status of the lake
- To identify major problems of the lake
- To assess the sedimentation rate of the lake, and
- To determine the isotopic characteristics of the lake

## 2.0 REVIEW OF LITERATURE

A number of studies have been reported on isotopic application to lake studies particularly lake sedimentation and lake ground water interaction, some of these are discussed below.

Instrumentation and methods exist for highly precise analyses of the stable-isotopic composition of organic compounds separated by GC. The general approach combines a conventional GC, a chemical reaction interface, and a specialized isotoperatio mass spectrometer (IRMS). Most existing GC hardware and methods are amenable to isotope-ratio detection. The interface continuously and quantitatively converts all organic matter, including column bleed, to a common molecular form for isotopic measurement. C and N are analyzed as CO<sub>2</sub> and N<sub>2</sub>, respectively, derived from combustion of analytes. H and O are analyzed as H<sub>2</sub> and CO produced by pyrolysis/ reduction. IRMS instruments are optimized to provide intense, highly stable ion beams, with extremely high precision realized via a system of differential measurements in which ion currents for all major isotope logs are simultaneously monitored.

Soil erosion is a serious environmental problem. Traditional methods used to measure soil erosion are time consuming and the results obtained for an experimental plot are usually incomparable with one another. The use of <sup>137</sup>Cs to measure soil erosion overcomes some of the limitations of the traditional methods (Stach, 1996). These methods are a valuable alternative compared to the traditional methods. <sup>137</sup>Cs measurements can be used as a basis for studying both the spatial variability of soil loss and its magnitude. This method can be used also for identifying sediment sources (Walling and Quine 1991; Wallbrink and Murray, 1993; Wallbrink et al., 1999; Olley et al., 1993). The first attempts to use <sup>137</sup>Cs measurements for estimation of soil erosion were carried out in the 1960-ties (Yamagata et al., 1963; Rogowski and Tamura, 1965) and since then ceasium-137 has been used to study soil erosion and deposition. Caesium <sup>137</sup>Cs is a fission product, it is a gamma emitter with energy of 661.6 keV and its half-life is 30.02 years. These properties make the <sup>137</sup>Cs isotope a valuable tracer of soil erosion in the medium term. In addition, the counting of the sample is very easy. For the last 35 years, the fallout of <sup>137</sup>Cs has been widely used as an environmental tracer to study soil erosion (Ritchie and McHenry, 1990; Zapata, 2003).

Existing methods of quantifying soil loss, such are erosion plots possess many limitations in terms of cost, representativeness and the reliability of resulting data (Loughram, 1989; Evans, 1995). These methods are also generally unable to provide the detailed spatially- distributed data required to verify the new generation of distributed erosion and sediments yield modles (Morgon et al; 1998; De Roo et al; 1989; Nearing et al; 1989) and to interface with currents developments in the application of GIS and geo-statics to this field. Recent work in exploring and exploiting the potential for using environmental radio-nuclides, and more particularly <sup>137</sup>Cs, to document rates and patterns of soil redistribution by erosion processes (Ritchie and Mc Henry, 1990; Walling and Quine, 1993; walling 1998) can, however, now be seen as offering important new opportunities in this area.

Despite the reported environmental issues, no systematic studies have been reported for the Rewalsar lake. However, a few scattered referreces on the lake are available. Das

and Gaye-Haake (2003) studied the geochemistry of Rewalsar Lake sediment and analysed its implications for source-area weathering. Das and Dhiman (2003) studied the chemical characteristics of the lake. Das and Dhiman (2003) also reported the sediment chemistry of the lake.

Das and Haake (2003) have investigated the major, trace and rare earth element chemistry of the lake sediments. Their investigations reveal that the Chemical Index of Alteration (CIA) between 75.2 to 78.1 and Chemical Index of Weathering (CIW) between 79.5 to 89.8 are higher than Post-Archean Australian Shale (PAAS), indicating moderate to high weathering at source area. Plot of sediment chemistry of lakes on tectonic delineation diagrams show that Rewalsar detritus derived from middle Siwalik rocks are from passive margin setting. The discriminant function plots of sediment samples also indicate that they are derived from craton interior or a quartzose sedimentary orogenic terrain and deposited in a passive margin setting. The chemistry of Rewalsar sediments is thus a proxy for the middle Siwalik rocks deposited in the foreland basin and throw light on provenance, source area weathering, and tectonic setting of the source rock.

Thakur et al (2013) studied the limnobiological status of three selected lakes of Himachal Pradesh including Rewalsar Lake using physicochemical and biological parameters (especially phytoplankton and zooplankton) over a period of 2 years. One hundred forty-eight species belonging to nine groups of phytoplankton and 79 species belonging to five groups of zooplankton were identified from the lakes. Trophic level and the pollution status of the lakes were assessed upon the basis of Shannon diversity index ( $H'$ ), species richness index ( $S$ ), and physicochemical parameters. Plankton population size was correlated with biotic and abiotic parameters (pH, alkalinity, temperature, dissolved oxygen, transparency, phosphate, chloride, and nitrate). The investigation revealed that the distribution of plankton species depended upon the physicochemical parameters of the environment. Based on water quality standards given by the Central Pollution Control Board, the water quality was between "D-E" class at Rewalsar Lake. The results from the present study indicated that the potential of planktons as bioindicators of trophic status is very high.

According to study conducted by the Pollution Control Board in 2010, the oxygen level in the lake water was found 2 to 3 ppm. Moreover, due to pollution the nature of water has turned acidic (Tribune India, May 11, 2010). The poor sewerage system of Rewalsar own is further increasing the problem as contaminated water directly flows into the lake (Tribune India, May 11, 2010).

**Table 4: Water quality of Rewalsar Lake during April, 2009**  
(as per H. P. C. B.)

Parameter	Value
pH (mg/l)	7.14
BOD (mg/l)	1.3
T.C. (MPN /100ml)	>2400
D.O. (mg/l)	3.2

**Table 5: Water quality of Rewalsar Lake during July, 2009**  
(as per H. P. P. C. B.)

Parameter	Value
pH (mg/l)	7.06
BOD (mg/l)	4.2
T.C. (MPN /100ml)	>2400
D.O. (mg/l)	3.0

According to the news published in the Tribune (May 14, 2014), more than 700 fish died during May 2014 at Rewalsar Lake. According to local residents, the death of fish is a regular feature here as thousands of devotees overfeed them at the lake during Tsheshu and Baisakhi festivals. They said the leftover food contaminated the water as a result of which the dissolved oxygen level went down and the fish started dying. According to this news, "Contaminated water flows from the catchments area directly into the lake as a result of which fish die. Moreover, there is hardly any effective drainage system." The news further reports that the local residents claimed that some religious institutions had constructed septic tanks along the lake due to which the sewage flows directly into it, but no one had tried to stop the practice. They said they had raised the issue several times, but to no avail.

### **3. STUDY AREA**

Rewalsar Lake, or Tso Pema Lotus Lake, is a mid-altitude lake located on a mountain spur in Mandi district, 22.5 km south-west from Mandi in Himachal Pradesh. Its elevation is about 1,360 m above sea level. The lake is situated in Rewalsar town, 24 kilometres from Mandi district. It lies between 31°37'30" N and 76°49'15" E at an altitude of 1360 meters above sea level. It is a natural water body, multipurpose in use and shaped like a square with a shoreline of about 735 meter and 175 hectare catchment area. The maximum depth of the lake is 6.5 m. The lake is significant for religious, cultural and tourism purposes. However, due to unscientific and unplanned developmental activities of the catchment in the past, the lake has undergone severe eutrophication. The lake is held as a sacred spot for Hindus, Sikhs and Buddhists alike. With water, woodland and high hills, it presents a variety of natural beauty. There are three Buddhist monasteries at Rewalsar. The lake also has three Hindu temples dedicated to Lord Krishna, Lord Shiva and to the sage Lomas. The lake has been in live height in recent years due to death of fishes. Figure1 presents a view of the Rewalsar lake. Figure2 shows Google earth view of the lake.



**Figure 1:** View of the Rewalsar lake, Mandi **Figure 2:** Google Earth view of Rewalsar lake

The lithology is mid Siwaliks consisting of fine-grained, light coloured sand stones with silt- and clay interlayering. Flakes of mica are observable in siltstones. A thin clay rich soil has been formed on the Siwaliks. Similar to the Mansar the Rewalsar lake is oligotrophic. As it is a religious centre the environment has been kept largely in its pristine condition so that the anthropogenic imprint is even less than on the Mansar lake (Das et al., unpublished). The trace metal concentration in surface sediments are lower than the reference values of the PAAS (Post Archaean Australian Shale), NASC (North American Shale Composite) or UCC (Upper Continental Crust) so that they are considered to be derived from a crustal source (Gaye

Surface runoff flows to the lake through small streams and feeds the lake. Surface water flow into the lake is low except during the monsoons which are characterized by moderate to high precipitation in the areas.

As per the news published in the Triune, the Irrigation and Public Health Department had removed vegetation from around the lake which used to act as a natural filter and stop impurities from flowing into the lake directly. The department had constructed drains around the lake and even constructed a concrete structure around it. But due to ineffective drainage system, the polluted water of the town flows directly into the lake.

## **4.0 DATA AND METHODOLOGY**

In the present study catchment map of Rewalsar lake has been prepared using Arc GIS 9.3 and Google earth. The sedimentation in Rewalsar Lake has been studied using Cs-137 Dating Technology. Isotopic characteristics of the Rewalsar lake has been studied by studying the environmental isotopes. For the Isotopic analysis of water (Oxygen and Hydrogen) Dual Inlet Isotope Ratio Mass Spectroscopy are used. The analysis has been carried out at the Nuclear Hydrology Laboratory at NIH.

### **4.1 Determination of lake sedimentation rate using $^{137}\text{Cs}$**

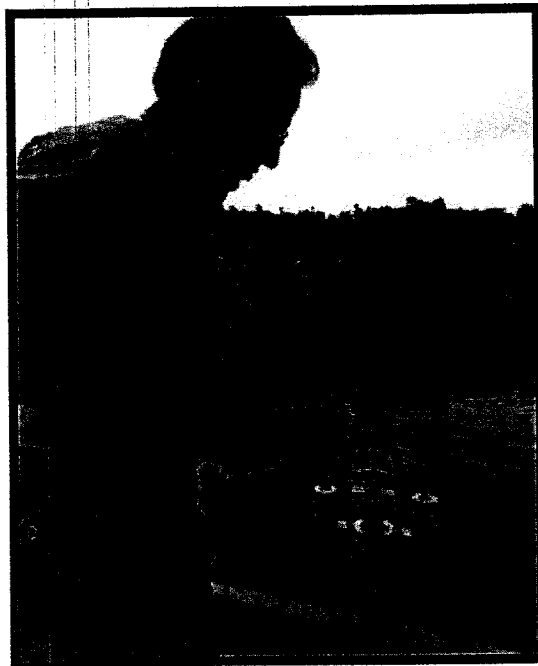
#### **4.1.1 General**

Radioactive fallout  $^{137}\text{Cs}$  (cesium-137) deposited across the landscape from atmospheric nuclear tests is strongly absorbed on soil particles limiting its movement

by chemical and biological processes. Most  $^{137}\text{Cs}$  movement in the environment is by physical processes; therefore,  $^{137}\text{Cs}$  is a unique tracer for studying erosion and sedimentation. By measuring spatial patterns or  $^{137}\text{Cs}$  in vertical and horizontal planes across the landscape, rates of soil loss or deposition can be measured for different parts of a watershed. Even within landscape units, redistribution of soil can be mapped and erosion or deposition rates for different parts or individual fields measured and mapped. Sediment accumulation rates can be measured by comparing the vertical distribution or  $^{137}\text{Cs}$  in sediments with the temporal deposition or fallout  $^{137}\text{Cs}$  from the atmosphere to locate sediment horizons. Using these dated sediment horizons, sediment accumulation rates can be measured. Interpretations about the location of these dated horizons must consider particle size of the sediments, reworking or deposited sediments, diffusional movement of  $^{137}\text{Cs}$ , and time rates of physical process in the sedimentation process. The  $^{137}\text{Cs}$  technique can be used to determine sediment accumulation rates in a wide variety of depositional environments including reservoirs, lakes, wetlands, coastal areas, and floodplains.

#### 4.1.2 Sediment sample collection

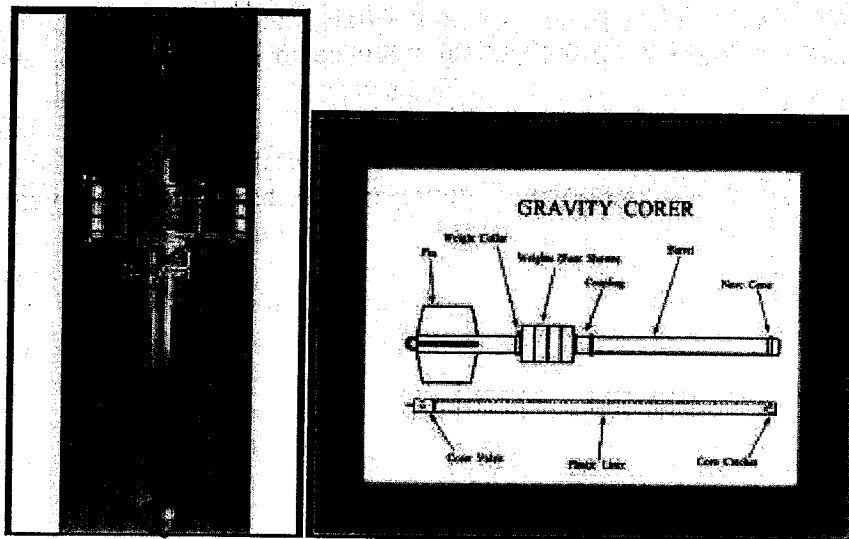
Combination of different factors such as velocity, turbulence, slope, depth of water column, size and nature of sediments etc bring about the variation in the rates of sedimentation of different parts of the lake. Therefore, for a more accurate estimation of rate of sedimentation in lake, sediment cores must be collected from different part of the lake based on distance from major inflow points, depth, bed slope, thickness of sediment layer, area of lake etc.



**Fig. 3: Sediment core collection from Rewalsar Lake**

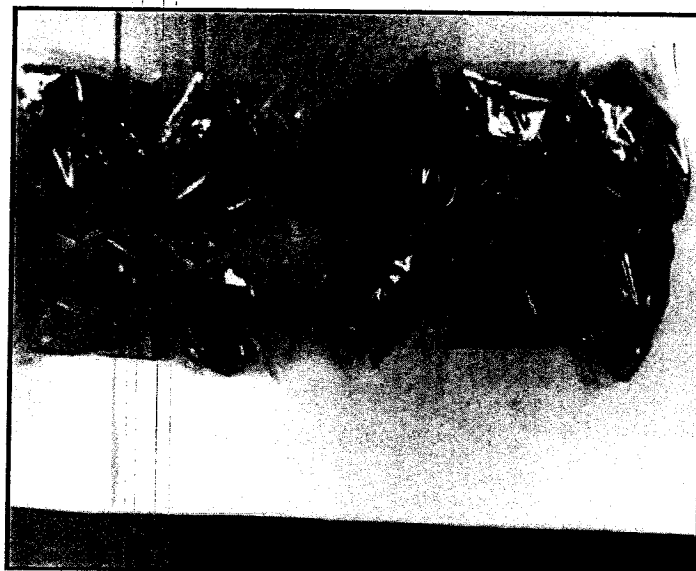
The sampler that is used presently at NIH is a gravity corer, supplied by KC Maskinger Laboratriudetyr, Denmark (Kajak corer). The sample corer consists of 22 kg counter

weights, with either 50 cm long sampling tube or 100 cm sampling tube. For extraction of the samples, an adjustable piston rod with silicone packing is also available. The internal diameter of the sampling tube is approx. 5 cm.



**Fig 4: Core sampler for sediment analysis**

No special preservation procedures are required for  $^{137}\text{Cs}$  dating technique. The collected cores are placed vertically and a light coloured opaque graduated adhesive tape may be fixed on the core tube, with the markings running from top to bottom. The total length of the sediment core has to be recorded in the sampling information sheet. Required number of sample storage device (polythene bags) may be numbered accordingly. The core is sliced into several sections of optimum thickness (usually 1 to 2 cm thick) with the aid of piston and a clean knife or any such sharp edged tool and stored in sample storage device.



**Fig 5: Sample Preservation**

### 4.1.3 Processing of Sediment Samples

#### a) *Determination of bulk density*

As soon as samples are transported to the lab, the samples have to be emptied into clean and dry stainless steel containers. The weight of empty container and weight of the container plus the sample are to be recorded.

The bulk density ( $\rho_b$ ) is calculated as:

$$\rho_b = W_w/V$$

Where,

$W_w$  = wet weight of sample (g)

$V$  = volume of the sample (cc)

Volume of a 2 cm section of sample is equal to 39.26 cm<sup>3</sup>

#### b) *Oven drying*

The steel container is then placed in the temperature controlled oven at a temperature of 120°C for removal of moisture.

#### c) *Determination of dry density*

The dry density ( $\rho_d$ ) may be determined as:

$$\rho_d = W_d/V$$

where,

$W_d$  = dry weight of the sample (g)

$V$  = volume of sample (cc)

#### d) *Determination of Moisture content*

The moisture content ( $Q$ ) is determined by:

$$Q = (W_w - W_d)/W_w$$

where,

$W_w$  = wet weight of the sample (g)

$W_d$  = dry weight of the sample (g)

#### e) *Powdering and sample homogenisation*

For radioactivity measurements the lumps have to be powdered and homogenised. This has been carried out manually by using the Pestle and Mortar that are cleaned with acetone and tissue papers regularly after every sample.



**Fig 6: Sample Processing (crushing and grinding)**

#### **4.1.4 Measurement of $^{137}\text{Cs}$ (cesium-137) activity**

The Cs-137 activity is measured using gamma spectroscopy. A typical analog HPGe detector-based gamma spectroscopy system consists of a HPGe detector, high voltage power supply, preamplifier (which is usually sold as part of the detector), amplifier, Analogue to Digital Converter (ADC), and Multi- Channel Analyzer (MCA). The function of the electronic system is the collection of the electrons produced from the signal pulses and the processing of those pulses and sorting them by height or energy.

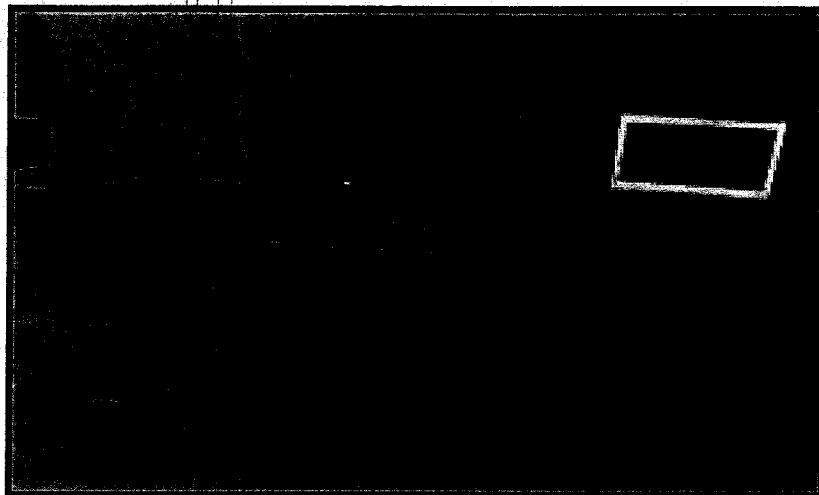
For measurement of  $^{137}\text{Cs}$  activity the EG & G ORTEC multi channel gamma ray spectrometer (MCA) is used. The connections between the HPGe detector and the MCA as well as that between the PC and the MCA are made. The SD slot in the MCA panel is shortened with a 50 ohm terminator. This is to bypass the requirement of a liquid nitrogen level controller that automatically shuts down the HV supply in case of very low level of liquid nitrogen (LN<sub>2</sub>).

The Priston Gamma Tech., USA converts the radioactivity incident on the Germanium crystal into analogue signal that is received by the MCA system. The system processes the input signal from the detector and sends the processed digital signal to the computer attached to the system the entire operation is controlled through the MAESTRO32 software supplied by EG & G. As the HPGe detector is very sensitivity to all types of radioactivity a heavy and thick lead shield is provided around the detector to reduce the radioactivity emitted from the surroundings.

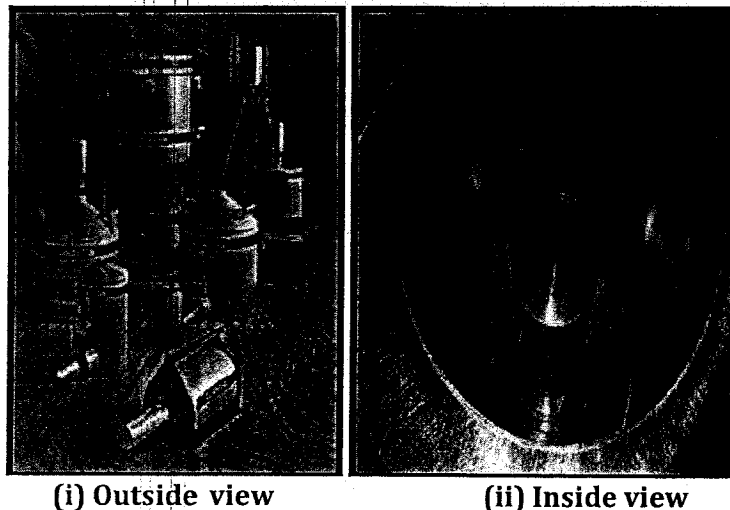
The various components of the gamma spectrometer are discussed below.

The detector is the centre piece of the gamma spectroscopy system. The gamma photons interact with the detection material and transfer their energies to electrons or to positrons in the case of annihilation. These produced particles loose their energy within the detector, creating ionized atoms and ion pairs. These secondary entities form

the basis of the detector signal. High purity Germanium is the mostly used material for gamma ray spectrometry systems.



**Fig. 7: Multichannel Gamma spectrometer used for radiometric dating Technique**



**(i) Outside view**

**(ii) Inside view**

**Fig. 8: Germanium Detector**

The charge created within the detector after the photon interaction with the detector crystal, is collected by the preamplifier. Most Germanium detectors in use today are equipped with RC feedback, charge sensitive preamplifiers. These can have various modes of operation: current sensitive, voltage-sensitive and charge sensitive. Charge-sensitive preamplifiers are commonly used for most solid state detectors.

The High Voltage Power Supply unit supplies the necessary high voltage to the detector and the necessary voltages to the rest of the system components. These units are usually able to supply up to 5000 V.

The multichannel analyzer (MCA) is the heart of most experimental measurements. It performs the essential functions of collecting the data, providing a visual monitor, and producing output, either in the form of final results or data for later analysis.

Genie 2000 is a comprehensive set of capabilities for acquiring and analyzing spectra from Multichannel Analyzers (MCAs). Its functions include MCA control, spectra display and manipulation, basic spectrum analysis and reporting. Optional capabilities include comprehensive spectrum analysis for alpha and gamma spectroscopy, quality assurance, system automation and turnkey packages for specific, dedicated applications.

The efficiency of the detector has been calculated as follows:

$$E = [(Gc - Bg) * 1000] / [72 * A * Ws]$$

where,

E is the efficiency (%); Gc is the gross counts in the ROI; Bg is the Background; A is the activity corrected for radioactivity decay (mBq/g); Ws is weight of the standard used for efficiency estimation (g). Presently IAEA - 300 Blastic sea sediment is used as standard at NIH Roorkee. 10 g of the standard is taken in Petri dish.

#### 4.1.5 Estimation of $^{137}\text{Cs}$ activity

The  $^{137}\text{Cs}$  activity in the sediment sample has been estimated by using the following equation:

$$A = [(Gc - Bg) * 1000] / [72 * E * Ws]$$

where, A is activity of sample (mBq/g), Gc is the gross counts in the ROI; Bg is the background counts in the same ROI; E is the efficiency (%) and Ws is weight of the sample used for activity measurement (g).

Once the  $^{137}\text{Cs}$  activity is determined in different sediment samples the activity is plotted and matched with the global fall out pattern to determine the peak corresponding to year 1964. The time elapsed since then is measured and the rate of sedimentation is determined from the depth of sediment deposited since the occurrence of peak. This is further discussed in the section on results and discussion.

## 4.2 Isotopic Characterization of the Lake

Variations in isotopic signatures of different sources of water are analyzed to interpret the various hydrological processes. Stable isotope variations result from isotope fractionation which occurs during physical and chemical processes. Examples of physical processes include evaporation or condensation. During evaporation, the residual liquid is enriched in the heavier isotope molecule because the lighter molecules move rapidly and hence has a greater tendency to escape from the liquid phase - there is a difference in the volatility between the two molecular species. Chemical fractionation occurs because a chemical bond involving a heavy isotope is stronger than that with light isotope. Within a region variation of isotopic composition is also

governed by various factors like altitude, amount of rain, etc. Seasonal variations in isotopes are mainly due to variation in temperature and change in amount of precipitation. Evaporation and evapo-transpiration increases with increase in temperature. Local or regional water vapours mix with the water vapours originated from the sea and enriches the precipitation in  $^{18}\text{O}$  and D. Increase in temperature increases the effect of evaporation in the falling raindrops and enriches the precipitation in D and  $^{18}\text{O}$ . This effect is least when precipitation occurs in large amount or with high intensity.

#### 4.2.1 Sampling and isotopic analysis

In order to understand the isotopic characteristics of the lake and the lake-ground water interaction aspect isotopic analysis of the various waters in and around the lake has been carried out. Water samples have been collected from various sources such as lake, inflow and surrounding ground water (handpumps ) (Fig. 9). Figure 10 shows the location of the isotopic sampling sites.



Figure 9: Lake water sampling for isotopic analysis



Figure 10: Location of sampling sites for isotopic analysis

The water samples have been analysed for  $\delta^{18}\text{O}$  and  $\delta\text{D}$ . The stable isotopes of oxygen ( $\delta^{18}\text{O}$ ) have been analysed using Continuous Flow Isotope Ratio Mass Spectrometer (CFIRMS) (Fig. 11.1) and stable isotopes of hydrogen ( $\delta\text{D}$ ) have been analysed using Dual Inlet Isotope Ratio Mass Spectrometer (DIIRMS) (Fig.11.2). The analysis has been carried out at the Isotope Hydrology Laboratory of NIH which is one of the best laboratories in India for the purpose.

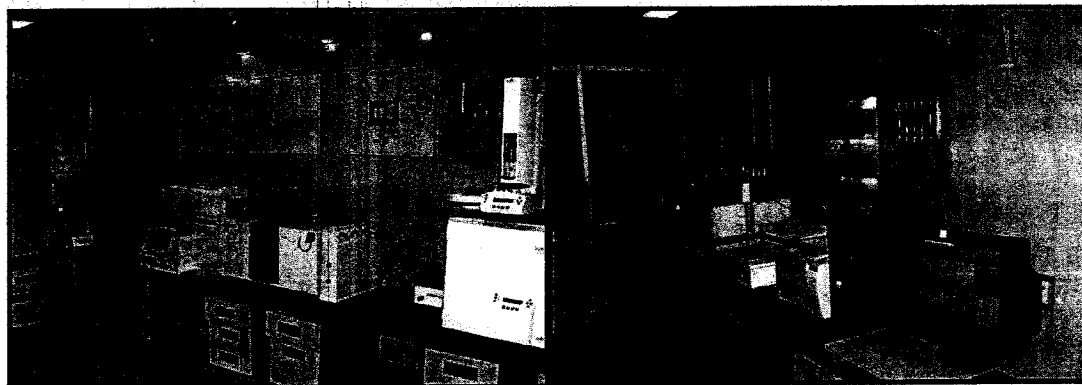


Fig. 11.1: CFIRMS at NIH

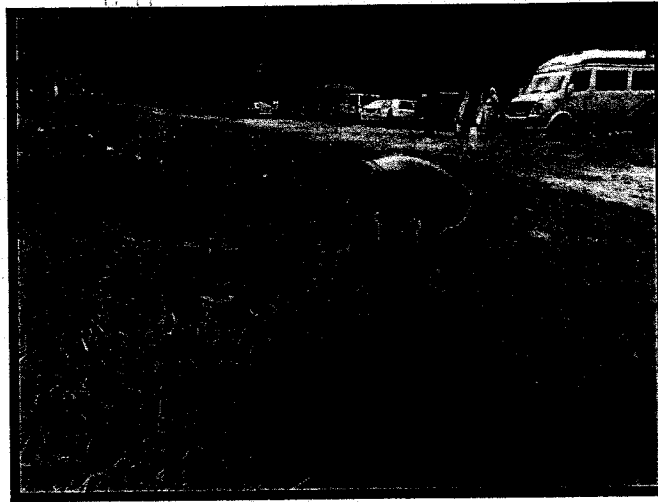
Fig. 11.2: DIIRMS at NIH

### 4.3 Water Quality Analysis

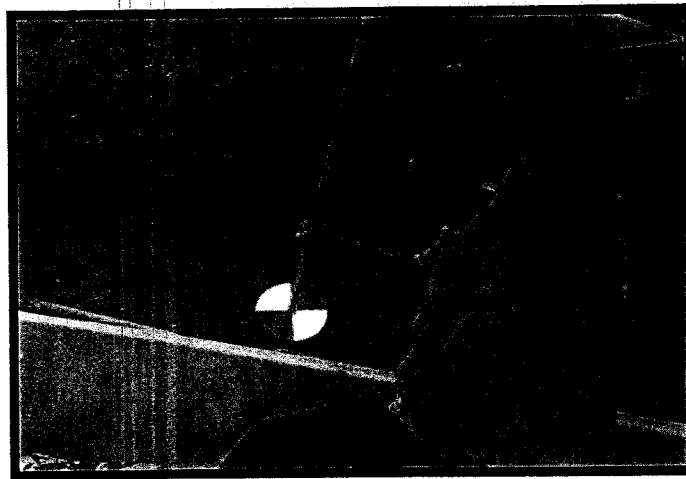
To determine the water quality status of the lake water quality sampling was carried out during the month of July 2105 (monsoon), January 2016 (winter) and June 2016 (summer). Water samples were collected from different sites of the lakes. The samples were collected in the 1 plastic (Polyvinyl propylene) bottles. The bottles were labeled R-A, R- B , R-C, R-D, E,F as Bottles were dipped completely in the water taking care to avoid mixing of air bubbles in water sample. The bottles were filled up to rim and screwed tightly.. They were refrigerated at  $4^{\circ}\text{C}$  and analyzed within 48 hrs. The water quality sampling sites are shown in Figure 12.



Fig. 12: Location of water quality sampling sites of the lake



**Fig. 13: Water quality sampling of Rewalsar lake**



**Fig. 14: Measurement of sechchi depth data of the lake**

## **5.0 RESULTS AND DISCUSSION**

### **5.1 Land use and land cover**

The land use/land cover maps have been prepared using ARC GIS software. The catchment area has been broadly classified into four major land use/land cover classes (i) Forest, (ii) built-up area (iii) barren land (iv) Agriculture and (v) Water body. Land use land cover classification of the lake is shown in Figure 15. The total area covered by each land use class and its percentage with respect to the total catchment area is shown in Figure 16. It can be seen that the total catchment area of the lake is 0.94 km<sup>2</sup> only. Barren land cover area contributes the maximum land cover of the lake catchment covering 0.36 km<sup>2</sup> which is about 38 % of the total catchment area. Forest area is the second most significant land use with a total area of 0.30 km<sup>2</sup> which is about 32% of the total catchment area. The area covered by the water body is 3.67 % (0.03 km<sup>2</sup>). Built up area is about 0.11 km<sup>2</sup> which

accounts for 11.3% of the total catchment area. Agriculture is practiced in 0.14 km<sup>2</sup> which is about 15% of the total catchment area

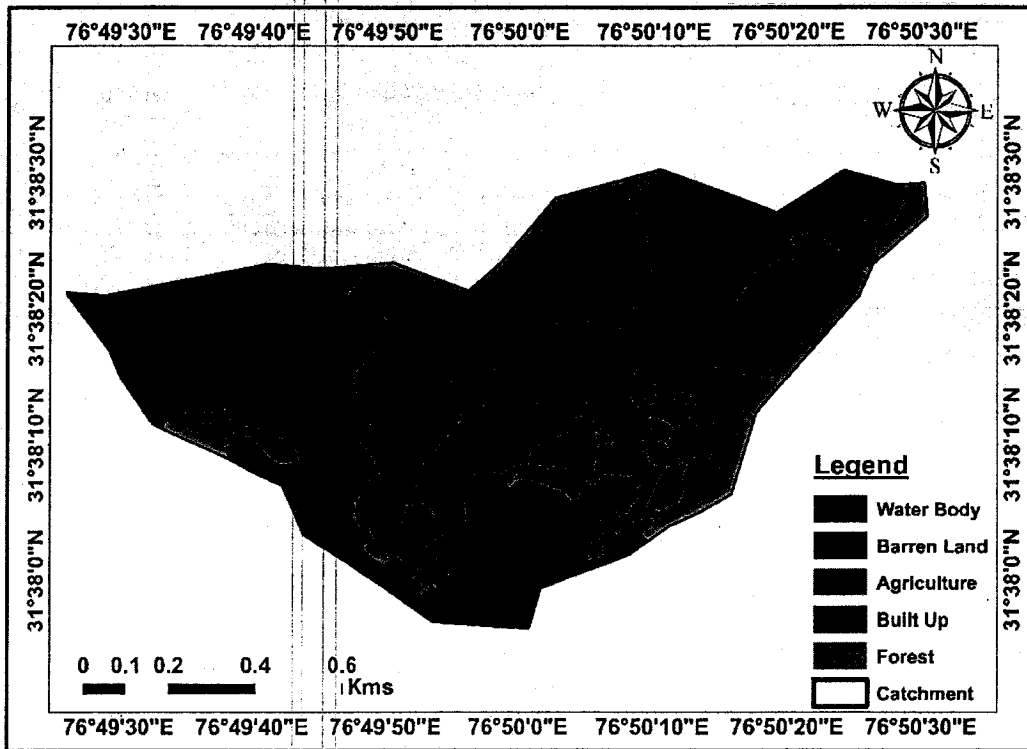


Figure 15: Land use and land cover map of the Rewalsar lake catchment

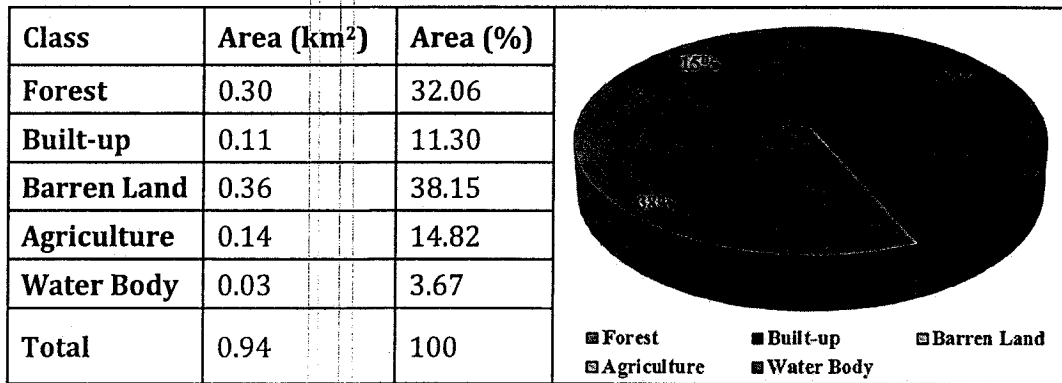


Figure 16: Statistic of land use and land cover of Rewalsar lake catchment

## 5.2 Estimation of rate of sedimentation

Each sediment sample obtained from the sediment core was analysed for Cs-137 activity and energy spectrum for each sample was obtained. An illustration for sample of depth 6-8 cm is shown in Fig 17 below:

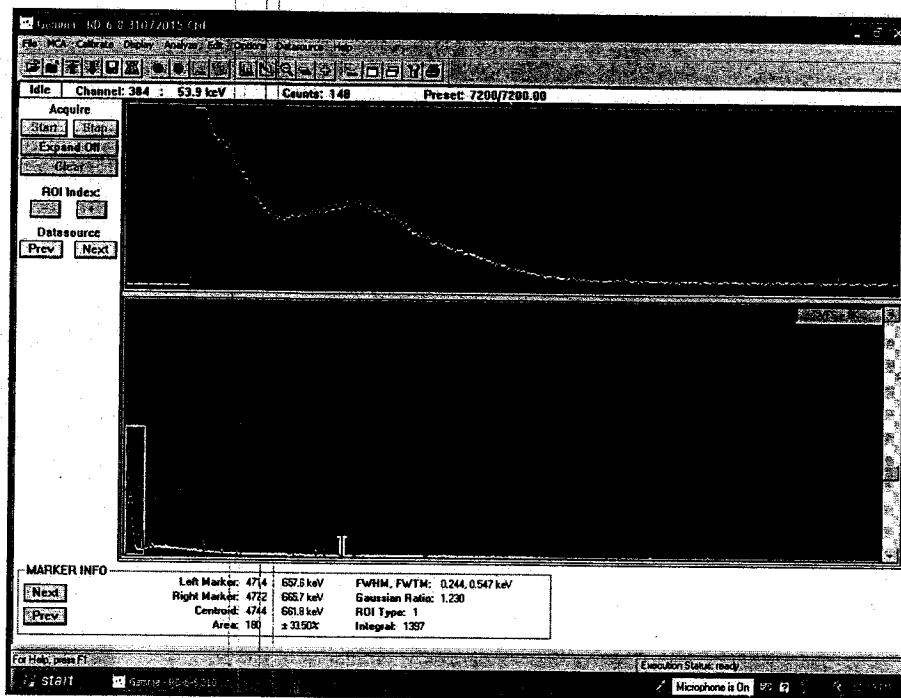


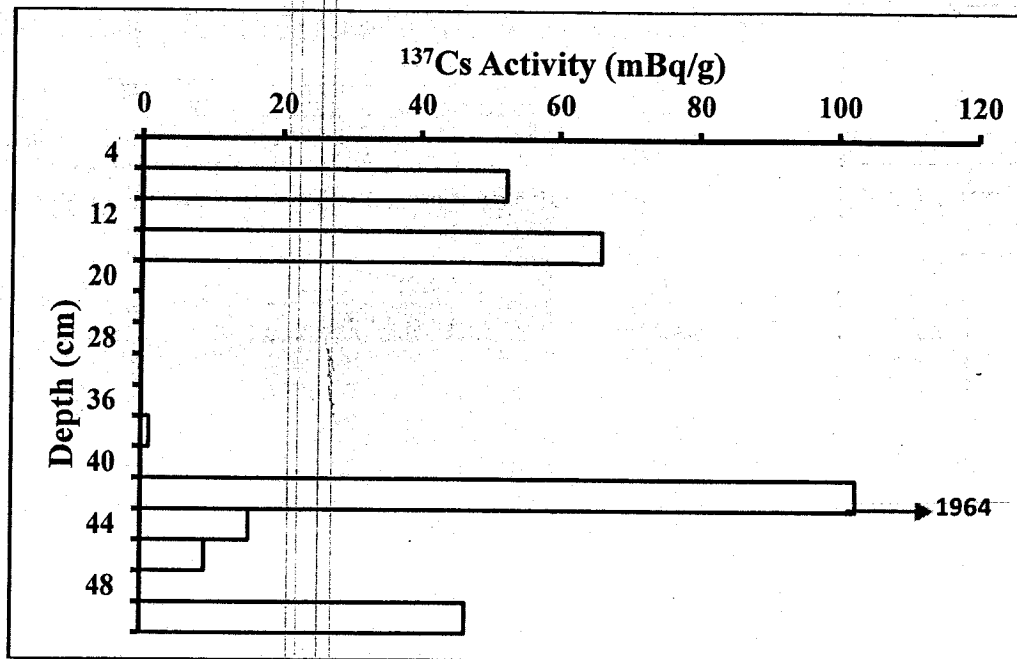
Figure 17: Spectrum obtained after analysis of sample

Result of activity obtained for each sample is shown in Table 5.

Table 6:  $^{137}\text{Cs}$  activity in different samples

Depth of sample in core (cm)	Depth of sample from surface of lake bed	Cumulative Thickness of sample (cm)	Sample Reference No.	Dry Weight	Efficiency of detector	Gross Area	Cs-activity (mBq/g)
44-48	0-4	4	16	6.13	2.44	0	0
40-44	4-8	8	15	10	2.44	92	52
36-40	8-12	12	14	10	2.44	0	0
32-36	12-16	16	13	10	2.44	116	66
28-32	16-20	20	12	10	2.44	0	0
24-28	20-24	24	11	10	2.44	0	0
20-24	24-28	28	10	10	2.44	0	0
16-20	28-32	32	9	7.38	2.44	0	0
12-16	32-36	36	8	10	2.44	0	0
10-12	36-38	38	7	10	2.44	2	1
8-10	38-40	40	6	10	2.44	0	0
6-8	40-42	42	5	10	2.44	180	102
4-6	42-44	44	4	10	2.44	27	15
2-4	44-46	46	3	10	2.44	16	9
0-2	46-48	48	2	10	2.44	0	0
Bottom	48-50	50	1	10	2.44	82	47

Once the  $^{137}\text{Cs}$  activity was determined for all the samples of the sediment core, a plot of activity in sample versus depth of the sample was plotted. It is shown in Figure 18.



**Figure. 18: Activity plot for samples in the sediment core**

After the activity plot is obtained for the core, the next step is identification of the peaks and matching with the global fall out pattern. Global studies on <sup>137</sup>Cs fall out reveal the following markets:

- i) Initial appearance during 1954/55
- ii) Marked increase during 1958/62
- ii) Maximum fallout during 1963/64

After obtaining the plot, the peaks were matched as per the global fall out pattern. The peak of 1963 is shown in Fig. 20 above.

After identifying and matching the peaks, with the global fall out pattern as discussed earlier, rate of sedimentation has been estimated by using the depth as a marker, as follows:

$$R_s = D_p / T_E$$

where:

$R_s$  = rate of sedimentation (cm/y)

$D_p$  = depth of peak occurrence (cm)

$T_E$  = time elapsed since the corresponding fallout event.(y)

$D_p$  is the depth of maximum peak occurrence of 1964 which is 42 cm in the present sediment core.  $T_E$ , the time elapsed since the occurrence of the maximum peak comes out to be 51 years (since 1964 to the date of sampling). So, the rate of sedimentation for the Rewalsar lake comes out to be 0.82 cm/year. Useful life of the lake comes out to be about 800 yrs.

### 5.3 Isotopic Characterization of the Lake

The results of Isotopic analysis for Rewalsar lake are shown in Table 7. The values of  $\delta^{18}\text{O}$  are observed to range between  $-1.79\text{‰}$  to  $-1.53\text{‰}$  while those of corresponding  $\delta\text{D}$  range between  $-12.65\text{‰}$  and  $-10.85\text{‰}$ . The surrounding groundwater shows different isotopic characteristics. For the surrounding groundwater (which includes samples from hand pumps and springs) the values of  $\delta^{18}\text{O}$  are observed to range between  $-6.28\text{‰}$  to  $-4.81\text{‰}$  while those of corresponding  $\delta\text{D}$  range between  $-38.94\text{‰}$  and  $-23.28\text{‰}$ . Thus, it can be observed that the values observed in the lake are highly enriched compared to the surrounding groundwater. This shows the evaporation effect on the lake water. The evaporation effect can be very easily seen in the graphical representation of the data shown in Figure 21. Both the lake samples and the groundwater samples fall near the LMWL indicating that both the lake as well as the catchment is locally recharged.

Table 7: Isotopic characteristics of Rewalsar Lake and surrounding ground water

Location	Date	$\delta\text{O}^{18}$	$\delta\text{D}$
R-A	15-07-2015	-1.53	-10.85
R-B	15-07-2015	-1.79	-12.65
R-C	15-07-2015	-1.73	-10.91
R-D	15-07-2015	-1.72	-12.36
R-HP-1	15-07-2015	-5.16	-28.95
R-HP-2	15-07-2015	-6.28	-38.94
R-HP-3	15-07-2015	-6.20	-35.25
R-HP-4	15-07-2015	-5.95	-33.89
R-SP-1	15-07-2015	-5.34	-27.87
RI	15-07-2015	-4.81	-23.58

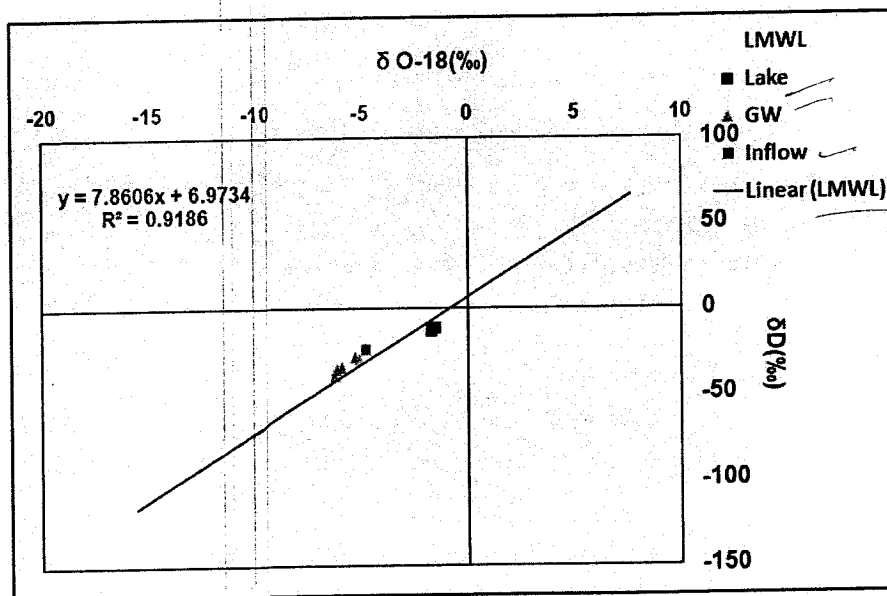


Figure 19: Graph of  $\delta^{18}\text{O}$  versus  $\delta\text{D}$  Rewalsar Lake

Isotopic analysis indicates that surrounding groundwater has different isotopic characteristics than the lake water. However, inflow water shows isotopic signatures similar to the surrounding groundwater. The highly enriched values of lake water compared to the surrounding groundwater indicates high evaporation rate of the lake during warm months.

For Rewalsar lake the sampling was done during 14<sup>th</sup> July, 2015. By this time there had been significant rainfall in the region. This depleted rainfall water when mixed with the lake water caused depletion of the isotopic values of the lake water. Another important reason is there are springs which fed the Rewalsar lake. The isotopic values of the springs are much depleted compared to the lake water, as can be seen from results for samples of R-SP-1 and RI. When this water mixes with the lake water its isotopic signature shows depletion.

### **5.3.1 Lake-Groundwater Interaction**

If we look at the isotopic data of Rewalsar lake, it can be seen that hand pumps samples (Sample R-HP-2 to R-HP-4) shows similar values. The  $\delta^{18}\text{O}$  value is around -6 ‰ and the  $\delta\text{D}$  value is around -35‰. The other ground water samples (R-HP-1, R-SP-1 and RI) also show similar values. Their  $\delta^{18}\text{O}$  value is around -5 ‰ and the  $\delta\text{D}$  value is around -28‰. The isotopic signature of first group of samples is depleted compared to the second group. It is possible that these two groups of samples belong to two different aquifers. Alternatively, it is also possible that the second group of samples indicate mixing of water from the lake which causes their enrichment. Further, detailed investigations with more data are needed to understand the interaction of Rewalsar lake with the surrounding groundwater.

## **5.4 Water Quality**

To determine the water quality status of the lake water quality sampling was carried out during the month of July 2105 (monsoon), January 2016 (winter) and June 2016 (summer). The results are presented in Tables 8, 9 and 10.

Results indicate that in general the lake water quality is good. Concentration of most of the water quality parameters at different locations in the lake vary in a low range, indicating well mixing of water. Also, seasonal variations are not significant except for DO. However, high DO (average value of 6.2-12.21 mg/l) along with very low value of BOD (average value of 0.73 mg/l) clearly indicates absence of organic pollution in the lake, particularly during monsoon and winter.

Analysis of the heavy metals was carried out to explore the possibility of contamination in view of the reported regular death of fish in the lake. The data are presented in Table 11. No significant contamination of any heavy metals has been observed.

**Table 8: Results of water quality analysis for monsoon season  
(July, 2015)**

Parameters	R-A	R-B	R-C	R-D	Average
pH	6.98	6.9	7.05	7.06	7.00
Water Temperature (°C)	27.7	28.1	27.4	27.8	27.8
EC	258	263	250	254	256.25
TDS	165	168	160	163	164.00
Alkalinity	NA	123.6	118.8	122	96.00
Total hardness	110.2	125.2	120.2	131.2	121.70
Calcium	83.6	84.2	87.4	95.4	87.65
Chloride	5.2	5.4	6.6	4.6	5.45
Nitrite	5.10	6.26	5.80	5.69	5.71
Nitrate	2.6	2.5	4.1	3.9	3.28
Fluoride	1.07	1.43	1.07	1.11	1.17
Sodium	23.93	25.33	24.13	22.8	24.05
Ammonium	1.02	NA	0.71	1.31	1.01
Potassium	13.46	15.16	12.88	12.84	13.59
Magnesium	5.36	4.84	4.96	4.75	4.98
Sulphate	5.33	6.29	1.56	1.23	3.60
D.O	14.4	NA	10.02	NA	12.21
B.O.D	1.2	0.2	0.8	NA	0.73

All parameters in mg/l except for pH and EC . EC is in  $\mu\text{S/cm}$

**Table 9: Results of water quality analysis for winter season  
(January, 2016)**

Parameters	July 2016	Jan. 2016			Average
		R-B	R-C	R-D	
pH	6.98	6.5	6.5	6.7	6.6
Water Temperature (°C)	27.7	12.4	13.3	12.6	13.0
EC	258	284	270	271	275
TDS	165	182	173	173	176
Alkalinity	NA	112	111	107	110
Total hardness	110.2	105	104	99	102.6
Calcium	83.6	32	33	31	32
Chloride	5.2	2	2	4	2.67
Nitrite	5.10	NA	NA	NA	NA
Nitrate	2.6	2.4	2.5	2.1	2.33
Fluoride	1.07	NA	NA	NA	NA
Sodium	23.93	6.8	7.6	8.0	7.47
Bicarbonate	NA	137	135	131	134.2
Potassium	13.46	2.0	2.1	2.0	2.03
Magnesium	5.36	6.1	5.2	5.3	5.53
Sulphate	5.33	2.0	1.0	1.0	1.33
D.O	12.21	5.6	7.4	6.2	6.4

All parameters in mg/l except for pH and EC. EC is in  $\mu\text{S/cm}$

**Table 10: Variation in water quality parameters during June, 2016**

Parameters	Value (mg/l)
pH	7.2
EC	268
TDS	160
D.O	7.4

**Table 10: Concentration of heavy metals (mg/l)  
In Rewalsar Lake (January, 2016)**

Element	R-B	R-C	R-D	Average
Ag	0.00023	0.00002	0.00003	0.00009
Al	0.00020	0.00044	0.00056	0.00040
As	0.00025	0.00006	0.00005	0.00012
Ba	0.00011	0.00008	0.00015	0.00011
Be	0.00003	0.00001	0.00001	0.00002
Bi	0.00450	0.00042	0.00015	0.00169
Cd	0.000019	0.000004	0	0.00001
Co	0.000003	0.000001	0.000015	0.00001
Cr	0.000086	0.000245	0.000087	0.00014
Cs	0.000024	0.000003	0.000001	0.00001
Cu	0.00057	0.000217	0.000125	0.00030
Fe	0.005002	0.003344	0.00583	0.00473
Ga	0.000114	0.000041	0.000006	0.00005
Hg	0.00405	0.000535	0.000212	0.00160

**Table 10...contd.**

Element	R-B	R-C	R-D	Average
In	0.00029	0.00002	0.00001	0.00011
Li	0.00000	0.00001	0.00003	0.00002
Mn	0.00040	0.00018	0.00037	0.00032
Pb	0.00009	0.00001	0.00001	0.00004
Rb	0.00005	0.00001	0.00000	0.00002
Se	0.00075	0.00031	0.00000	0.00036
Sr	0.00054	0.00036	0.00032	0.00041
V	0.00006	0.00003	0.00001	0.00003
U	0.00003	0.00000	0.00000	0.00001
Zn	0.00061	0.00129	0.00044	0.00078
Ti	0.01200	0.01100	0.00551	0.00950
Ni	0.00056	0.00037	0.00092	0.00062

Bacteriological characteristics of the lake are presented in Table 12. Total coliform value ranged between 240 and 2400 per 100 ml at the three locations. As far as faecal coliform is concerned, it was in the range of 210-280 MPN/100 ml at the three locations. Maximum MPN /100 ml value was seen in R-B followed by R-C AND R-A. Highest fecal coli form was observed at R-A. l

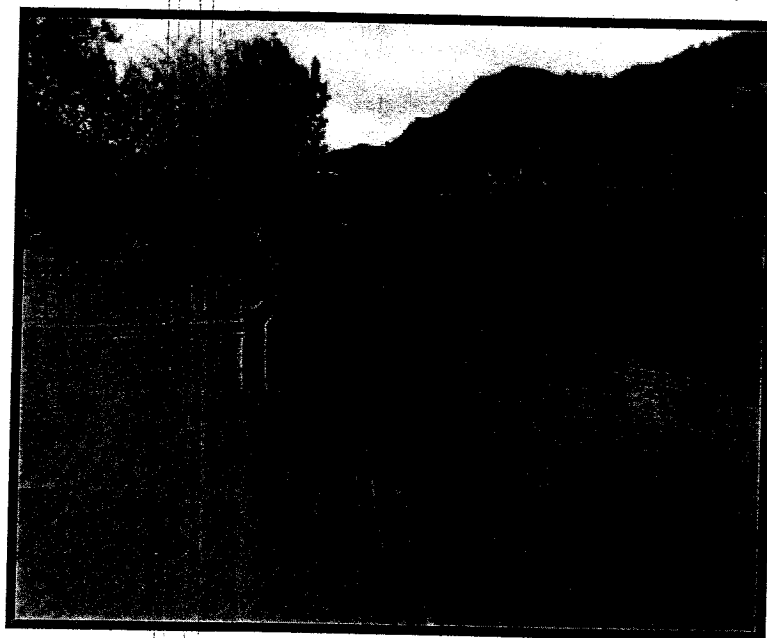
**Table 12: Bacteriological characteristics of the lake**

Location	Parameter	
	TC (MPN/100 ml)	FC (MPN/100 ml)
R-A	240	240
R-B	2400	210
R-C	460	280

Secchi disc data have been collected for the lake. It is shown in Table 13. It can be seen that the secchi disc depth varies in the range of 44 to 48 cm at all the four locations in the lake. The data shows that clarity of the lake is high, indicating less turbid water.

**Table 13: Secchi disc depth data for the lake**

Location	Secchi depth (cm)
RL-A	48
RL-B	44
RL-C	48
RL-D	44



**Figure 20: Feeding of fish at the lake**

## 6.0 CONCLUDING REMARKS

The study brings out that high sediment rate, fish kills in summer and management of cultural activities are the major issues for the lake. Lake is mostly ground water feed so the water quality is good. No geogenic pollution is observed. W.Q. analysis does not seem to relate the water quality with fish death. Sedimentation rate seems to be high but does not seem to be recent.

The study concludes that algal bloom during summer caused by nutrient supply from feeding causing possible reduction in DO, along-with overcrowding of fish and subsequent competition for DO during summer appear to be major cause of fish death. However, further detailed depth-wise monitoring of summer DO as well as detailed investigations by fisheries expert is required to establish the exact cause of fish death in the lake during summer.