WATER QUALITY AND HEAVY METALS LOAD IN SEDIMENTS OF NATURAL LAKES OF NAINITAL

Thesis

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CERTIFICATE

This is to certify that the thesis entitled **"WATER QUALITY AND HEAVY METALS LOAD IN SEDIMENTS OF NATURAL LAKES OF NAINITAL"** submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** with major in **Soil Science** and minor **Agricultural Chemicals** in of the College of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Mr. Ajay Pratap Singh, Id. No. 27724**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation has been duly acknowledged.

(P.C. Srivastava)
Chairman
Advisory Committee

C E R T I F I C A T E

We, the undersigned, members of the Advisory Committee of **Mr. Ajay Pratap Singh, Id. No. 27724**, a candidate for the degree of **DOCTOR OF PHILOSOPHY** with major in **Soil Science** and minor in **Agricultural Chemicals** agree that the thesis entitled **"WATER QUALITY AND HEAVY METALS LOAD IN SEDIMENTS OF NATURAL LAKES OF NAINITAL"** may be submitted in partial fulfilment of the requirements for the degree.

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INTRODUCTION

Introduction

"Our entire society rests upon and is dependent upon our water, our land, our forests and our minerals. How we use these resources influences our health, security, economy and well being"

John F. Kennedy

Water is the essence of life, which supports all the living organisms of this planet. The water is a universal solvent. Of late this vital resource is being over-exploited due to rapid industrialization, intensive agriculture and other anthropogenic activities, which have led to water pollution and cause various diseases. Overall, water health is at risk.

Oxford dictionary defines environment as the surroundings or conditions in which a person lives or operates. Pollution is a change in the characteristics of the air, water, soil and food that can adversely affect the health, survival or activities of humans or other living organisms (Miller, 1991). Although 'Pollution' has been defined variously but a more acceptable definition given by the Environmental Pollution Panel of the United States President's Advisory committee (1965), refers environmental pollution as the unfavorable alteration of our surroundings, wholly or largely as a byproduct of man's action, through direct or indirect effect of the changes in energy pattern, radiation level, physical and chemical constitution and abundance of organisms. These changes may affect man directly or through the supplies of water and agricultural and other biological products, his physical objects or possession or his opportunities for recreation and appreciation of nature.

Among the different components of environments, water is the most essential commodity for humans. It is one of the renewable resources which must be prevented from deterioration in quality. The water quality of various water bodies in India is greatly influenced by burgeoning population, development and the intensive high-tech cultivation. Natural lakes in India are getting polluted through tourist activities because most of the lakes are situated near historical places or hill stations. Lakes have a more complex and fragile ecosystem as they do not have self-cleaning ability and therefore, readily accumulate pollutants. These lakes are gradually becoming polluted by anthropogenic interferences. Run-off from agricultural lands, municipal and industrial waste waters not only influences the micro-fauna and flora of fresh water but also favour the eutrophication which means excessive growth of plants in water bodies. Eutrophication makes them unfit for swimming, boating and fish culture. Since the quality of water affects our lives in many ways, water must be of good quality for healthy survival of organisms. Water quality can have a great influence on the ability of aquatic plants and animals to exist and grow in a stream, pond or lake. Since water contains both the dissolved and suspended constituents in varying proportions, it often has different chemical and physical properties. Various physico-chemical properties like pH, electrical conductivity, hardness, dissolved oxygen, nitrate, calcium, chloride etc. play a significant role in determining the water quality. Several workers have studied the physico-chemical properties of different lakes and reservoirs in different parts of India (Patil *et al.,* 2004, Kulshrestha *et al.,* 1992).

Heavy metals (broadly defined as a group of toxic metals and metalloids associated with pollution and toxicity) are those which have density more than that of iron (Alloway, 1990). Operationally, all the micronutrient cations viz. iron, manganese, copper, zinc and nickel are classed as the heavy metals and depending on their levels in the plants/organisms exhibit either deficiency or toxicity. In addition, lead, cadmium, chromium, mercury, selenium and arsenic are the other heavy metals and metalloids which exhibit only toxicity to animals including human beings, and plants. Reports of infamous *Itai-Itai* and *Minamata* diseases from Japan due to excessive dietary intake of cadmium and mercury by human beings, respectively (Asami, 1981), are the examples of heavy metals pollutions. Health hazards associated with lethal intake of cadmium included renal (kidney) damage, anemia, hypertension, and lever damage (Nordberg, 1974). Mercury levels in human beings have been directly related to ingestion of fish reared on mercury polluted aquaculture, although agricultural use of mercurial fungicides can also cause entry of mercury into human system through crop plants (Asami, 1981). In Japan, the polished rice grain containing 1 ppm Cd and fish containing more than 0.4 ppm Hg (or 0.3 ppm methyl mercury) have been declared unfit for human consumption (Kitagishi and Yamane, 1981). Excess copper-induced molybdenum deficiency in the fodder leading to molybdenosis in the livestock is a case of heavy metal pollution occurring via contamination of the food chain. In light of all these reports, heavy metals have been classed as the dreaded pollutants which have potential of affecting human health via soil solid- soil solution- water-plant roots-edible parts- animal continuum.

In recent years, heavy metals in particular, have received great attention because they provide a coded history of lake's environment (Riggey *et al.,* 1982; Pennington, 1982; Forstner, 1976; Forstner and Wittamann, 1981; Sivakumar *et al.*, 2000). The properties which contribute to the deleterious effect of metals as environmental pollutants are: firstly that they cannot be destroyed through biological degradation as is the case with most organic pollutants and secondly, these metals tend to accumulate in the environment especially, with bottom sediments of rivers and lakes by association with organic and inorganic matter through processes of adsorption; complex formation and chemical combination (Forstner and Prosi, 1979). According to Zulling (1956), sediments are important indicators of anthropogenic activities. In our country where the majority of water bodies are invariably polluted by domestic and industrial effluents, quantification and mechanism of metal flux across the sediment-water interface are essential for better understanding of the cycling of these metals in the aquatic ecosystem.

Nainital is a well known tourist destination since British time. Nainital was developed as hill resort, education centre and administrative headquarter by the British. The tourist's inflow has increased in the region due to more emphasis given to tourism by the Uttaranchal Government. The Nainital district has a vast beautiful lake regions comprising mainly two lake regions viz., Nainital lake region (Nainital, Khurpatal etc.) and Bhimtal lake region (Bhimtal, Naukuchiatal, Sattal etc.). Owing to its rich biodiversity, this region is regarded as an ecological paradise which is currently threatened by ecological degradation due to excessive construction and tourist activities. These lakes are loosing their attraction, glory and original beauty due to undesirable anthropogenic activities such as throwing of plastic bags, cans, bottles, rags and other food materials and also by cloth washing , bathing, utensils cleaning etc. Therefore, the present study was undertaken with the following objectives:

- To evaluate the seasonal variations in the water quality of different natural lakes of Nainital.
- To examine the potential use of water for irrigation/ drinking purpose.
- To evaluate the seasonal variations in heavy metals pollution in waters and sediments.
- To study the relationship between physico-chemical properties of sediments with different chemical fractions of metals in sediments.
- To establish the relationship between concentrations of cations, anions and heavy metals in waters with physico-chemical properties of waters and also with different chemical fractions of heavy metals in the sediments.

REVIEW
of
LITERATURE

Chapter 2

Review of Literature

The problem of pollution is as old as the history of civilization. In the past, when the population was scanty, the degree of environmental pollution was limited and there was also ample scope for the natural purification. With increasing population and consequent intensive human activities, the situation has deteriorated progressively. The basic needs of human beings have disturbed the base of natural resources. The pollution of aquatic ecosystem has been a problem of growing concern in recent years. Water pollution is the state of deviation from the pure condition whereby its normal functional properties are affected. Lakes have limited self-cleaning ability and therefore, readily accumulate pollutants.

The literature pertaining to the present investigation has been reviewed and presented under the following sections:

2.1 Sources of water pollution

2.1.1 Sources of heavy metal pollution in waters and sediments

2.2 Drinking water standards

2.3 Physico-chemical characteristics of waters

2.4 Microbial pollution in waters

2.5 Heavy metal pollution in waters

2.6 Heavy metal pollution in sediments

2.1 Sources of water pollution

The common sources of water pollution can range from purely natural to several man-made sources like discharge of domestic and industrial waste-waters.

Natural Sources and Run-off

The natural entry of pollutants in water bodies can take place through rain; dry deposition from atmosphere, entrapment and reaction; periodic submergence of surrounding vegetation, and falling of dry plant parts from nearby vegetation directly on the surface of water. The run-off waters originating from different areas are often quits rich in nutrients and organic matter.

Human Activities

Human activities like bathing, swimming, washing cloths and utensils add considerable quantities of chemicals, Na and other elements in the lake water. Throwing of plastic bags, cans, bottles, rags and other food materials in the lakes and other fresh water bodies also contribute significantly to pollution.

Domestic Sewage

Sewage consists of waterborne wastes of the community, and contains about 99% of water and 1% of solids. Of the organic constituents, 65% are proteins, 25% carbohydrates and 10% fats. The major problems associated with sewage are the production of odours and spread of enteric diseases. Organic pollution also leads to oxygen depletion and causes fish kill. Sewage also contains huge quantities of nutrients in the form of nitrogen and phosphorus that often results in the problem of eutrophication.

Agricultural Wastes

Agricultural wastes usually originate in the form of run-off from the agricultural fields and animal farms. All the residues of agrochemicals along with organic debris from the remains of the harvested crops are trapped by run-off water and cause pollution problems in the receiving water body.

2.1.1 Sources of Heavy Metals

The term heavy metals refer to all metals with atomic number greater than 23 and specific gravity more than five (Albert and Winkinson, 1970). The sources of heavy metal in environment can be both natural and anthropogenic in origin. With the exception of soils, which are derived from physically and/or chemically weathered products of parent materials, most heavy metals added to the environment are result of anthropogenic activity (Patterson, 1971). The important sources of heavy metals include domestic sewage sludge, mining and smelting, fertilizers and pesticides, auto-emission, pulp and paper mill, brass, electroplating and other industrial wastes (Mohammad and Najar, 1997; Ross, 1994).

Parent Material

All soils naturally contain trace level of heavy metals. The concentration of metals in non-contaminated soil is primarily related to the geology of parent materials from which the soil was formed (USEPA, 1992). Shales and clays tend to have relatively high concentrations of heavy metals due to their high adsorptive capacity for these metals, while sandstone and lime-stones contain low metal concentration due to their low adsorptive capacity of metals (Alloway, 1990). Several easily weathered minerals from igneous and metamorphic rocks including olivine, hornblende and augite, contribute significant quantities of Fe, Zn, Cu, Ni and Pb to soils (Alloway, 1990).

Autoemissions

Alkyl lead (eg-Tetra ethyl lead) compounds used as antiknock in automobiles are some of the most important source of Pb in air. Niragu and Pacyna (1988) reported that worldwide emission of Pb into the atmosphere in 1983 was up to 248×10^6 kg $year^{-1}$ mainly due to alkyl lead compounds.

Mining and Smelting

Increased metal pollution results in heavy metal contamination in the vicinity of mining and smelting areas due to the discharge of effluent (Patterson, 1971).

Fertilizers and Pesticides

Several fertilizers contain small amount of metals such as Cd and Zn etc. Beside these, metals based pesticides including rodenticides, insecticides, fungicides and herbicides are widely used in modern agriculture which act as a source of heavy metal pollution (Adriano, 1986).

Sewage Sludge

According to Niragu and Pacyna (1988), sewage sludge applied to agricultural land to supply essential nutrients such as NPK (nitrogen, phosphorus and potassium) and some trace metals, contain elevated concentrations of many heavy metals such as Zn, Ni, Pb, Cu and Cd to increase their concentration in agricultural land.

Other Sources

These include energy production devices (emission from power station), secondary metal production and recycling operations eg. Melting of scraps, alloying, plating, metal washeries, brass manufacture, other industrial wastewater (Ravera, 1978).

2.2 Drinking water Standards

In view of the direct consumption of water by human beings, the potable use of water is considered to be most critical use of water. In India, agencies like the Indian Council of Medical Research (ICMR), Bureau of India Standards (BIS) and Ministry of Works and Housing (MWH) have formulated certain drinking water standards. The World Health Organization (WHO) and United States Public Health have also laid down drinking water standards. Standards as prescribed by WHO are considered to be of international standards. Upper permissible limits for irrigation water are also suggested by several workers. Drinking water standards and limits for irrigation water laid out by different agencies are given in Table 2.1.

2.3 Physico-chemical characteristics of water

A large number of pollutants can impart colour, taste and odours to the receiving waters, thus, making them unaesthetic and even unfit for domestic consumption. The changes in oxygen, temperature and pH affect the chemistry of waters are often triggering chemical reactions leading to the formation of unwanted products.

Table 2.1 Drinking water standards and limits for irrigation water

Parameters	Drinking water standards				Limits for irrigation water
	IS: 10500 BIS	MWH	WHO	USPH	
pH	6.5-8.5	7.0-8.5	6.5-8.5	6.5-8.5	-
CO_3^{2-}	-	-	-	-	-
HCO_3^-	-	-	-	-	-
Alkanity	200	-	-	-	-
E.C.	1500	750	-	300	2.0-10.0$
TS	-	500	500	-	
TDS	500	-	-	500	0-700**
TSS	-	-	100	5.0	-
DO	5	-	>6	4-6	-
BOD	3	-	-	-	-
COD	-	-	4	-	-
NH_4^+-N	-	-	1.5	0.5	-
K	-	-	-	-	-
Na	-	-	200	-	-
Ca	75	75	75	100	-
Mg	30	30	30	30	-
TH	300	200	100	-	-
NO_3^--N	45	45	45	<10	-
PO_4^{2-}	-	-	2-3	0.1	-
SO_4^{2-}	200	200	250	250	0-480**
Cl^-	250	200	250	250	0-355**
Fe	-	0.05	0.3	<0.3	5.0-20.0¥
Zn	-	5	3.0	5.5	2.0-10.0¥
Cu	-	0.05	0.05	-	0.2-5.0¥
Mn	0.1	0.05	0.05	<0.05	0.2-10.0¥
Ni	-	-	0.02	-	0.2-2.0¥
Pb	0.05	0.01	0.01	<0.05	5.0-10.0¥
Cd	-	0.01	0.003	0.01	0.01-0.05¥
Cr as Cr^{6+}	-	0.05	0.01	0.05	0.1-1.0¥
Total bacteria /100 ml	-	-	-	1×10^6	-
MPN/100 ml	500	0	0	10	-
SAR	-	-	-	-	10.0-30.0$
RSC	-	-	-	-	2.0-5.0$

*All values in mg L^{-1} except pH, EC (in $\mu S\ cm^{-1}$), SAR and RSC (me L^{-1}).

Sources: $ Paliwal and Yadaw (1976)

** CPCB (1979)

¥ Ayers and Westct (1976)

Various physico-chemical properties like pH, electrical conductivity, total dissolved solids (TDS), total suspended solids (TSS), hardness, alkalinity, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), concentration of anions and cations have a significant role in determining the water quality. Several studies have been done on the physico-chemical properties of waters from different lakes and reservoirs in India and abroad.

2.1.1 pH, carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and alkalinity

The pH is an important factor which controls the chemical changes, species composition and the metabolic activities of living organisms inhabiting the water bodies (Radhika *et al.*, 2004). The pH is an indicator of water which can harm animals and plants. According to Spence (1967), the pH of a typical oligotrophic lake ranges from 4.8 to 8.0 and of a eutrophic lake from 7.7 to 9.6. Sum of the carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions constitutes the total alkalinity of the water as temporary hardness and raises its pH to more than 7.5. The pH of water is principally governed by the carbon dioxide–bicarbonate–carbonate system (Hutchinson, 1975). The pH, carbonates and bicarbonates form a complex buffer system in the medium and the fluctuations in one may be reflected on the other, thereby showing either a direct or indirect relationship between any two of these parameters.

Alkalinity is measure of buffering capacity of the water and is important for aquatic life in a fresh water ecosystem because it equilibrates the pH changes that occur naturally due to photosynthetic activity of aquatic plants (Kaushik and Saksena, 1989). Alkalinity value

Table 2.2 pH, carbonate (CO_3^{2-}), bicarbonate (HCO^-) and alkalinity of waters from various lakes

Name and location of lakes	pH	CO_3^{2-} (mg L^{-1})	HCO_3^- (mg L^{-1})	Alkalinity (mg L^{-1})	References
Kaptai lake, Bangladesh	7.04-7.21	-	-	-	Khan and Chowdhary, 1994
Hanumanantal, Jabalpur	7.41-7.68	-	-	95.62-201.25	Dhamija and Jain, 1995
Barwani pond, M.P.	7.20-8.20	-	-	85-115	Mahajan and Kanhere,1995
Saroor Nagar lake, Hyderabad	8.30-9.20	43.2-113.4	247.1-898.6	-	Paka and Rao, 1997
O. U. campus pond, Hyderabad	7.40-9.00	0.0-64.8	98.9-296.5	-	Paka and Rao, 1997
Banjara lake, Hyderabad	8.20-9.70	16.2-86.4	71.3-269.5		Paka and Rao, 1998
Upper lake, Bhopal	7.25-8.90	0.0-3.6	0.0-6.1		Tiwari, 1999
Taudaha lake, Kathmandu	7.30-8.00	-	-	156-191	Bhatt *et al.*, 1999
Mariut lake, Egypt	7.40-8.50	-	-		Khalil, 2000
Marlimund and Pudumund lake, Ooty	6.90-7.90	-	-	9.5-115	Sivakumar *et al.*, 2000
Gadchiroli lake, Maharashtra	8.06-8.08	-	-	412.10-418.72	Patil and Tijare, 2001
Subhas Sarobar lake, East Calcutta	7.30-9.00	-	-	103-158	Saha *et al.*, 2001
Rankala lake, Kolhapur	7.34-8.90	-	-	121.33-265.45	Rasool *et al.*, 2003
Padamalaya lake Jalgaon, Maharashtra	7.48-8.37	-	-	133.33-141.25	Patil *et al.*, 2004
Naregal tank, Haveri, Karnataka	8.11-8.61	20-40	15-80	40-100	Kudari *et al.*, 2004
Vellayani lake, Thiruvananthapuran, Kerala	6.52-7.2	-	-	1.37-1.93 moles L^{-1}	Radhika *et al.*, 2004

provides a guideline for applying proper dose of chemicals in water and wastewater treatment processes.

Most of lakes are having neutral to alkaline pH. Katpai lake, Bangladesh; Hanumanantal, Jabalpur and Vellayani lake, Kerala were having neutral pH whereas other lakes and tanks had neutral to highly alkaline pH (Table-2.2). The content of carbonates and bicarbonates, in various lakes varied from nil to 113.4 mg L^{-1} and nil to 898.6 mg L^{-1}, respectively. The alkalinity varied from 9.5 to 418.72 mg L^{-1}.

The alkaline pH of lake water may be due to the presence of some alkaline substances used by people for washing of clothes and utensils. It may also be due to the presence of carbonate containing minerals in the sediments and surrounding soils. The pH and carbonates fluctuated directly whereas, pH and bicarbonates had shown a negative relationship (Paka and Rao, 1997). Seasonally, maximum pH was found during summer season and minimum was recorded during monsoon seasons (Katpai lake, Taudaha lake, Barwani tank and Vellayani lake). The carbonate, bicarbonate and alkanity were also maximum during summer and minimum during monsoon season.

High pH in summer resulted from increased photosynthesis and evaporation of water (Khan and Chowdhary, 1994). A similar effect can also be produced by water evaporation through the loss of half bound CO_2 and precipitation of monocarbon. Photosynthetic assimilation of dissolved inorganic carbon could also increase pH (Farrell *et al.*, 1979; Goldman, 1972 and King, 1970). Low values of pH during monsoon season might be due to dilution of water as a result of precipitation, a decrease in the population of phytoplankton and consequent reduction in productivity (Radhika *et al.*, 2004).

On the other hand, some lakes had maximum pH during monsoon season and minimum pH during winter season while during summer it was found to be intermediate (Saroor Nagar lake, Subhas Sarobar lake, Rankala lake and Naregal tank).

2.1.2 Electrical conductivity (E.C.), total solids (T.S.), total dissolved solids (T.D.S.) and total suspended solids (T.S.S.)

According to Wilcox (1950), electrical conductivity is one of the vital parameters to assess the quality of water. Electrical conductivity is a measure of the capacity of water to conduct electricity a it increases with increasing ion concentration. The changes in EC of water reflect proportional changes in ionic concentrations. Electrical conductivity is a fairly good and rapid method to measure the total dissolved solids and is also directly related to total solids.

Solids refer to the matter that remains as residue upon evaporation after drying at a definite temperature. Total solids (TS) are the residues that include both dissolved and suspended solids. Total dissolved solids (TDS) comprise mostly inorganic salts and small amount of organic matter whereas, total suspended solids (TSS) consists of particles of different sizes ranging from coarse to fine colloidal particles of various organic complexes and plankton. According to Rao (1970), alkaline ponds were richer in solids than acidic ones. In general, the quantity of solids is proportional to the degree of pollution (Marker, 1977).

Table 2.3 Electrical conductivity (E.C.), total solids (T.S.), total dissolved solids (T.D.S.) and total suspended solids (T.S.S.) in waters of some lakes

Name and location of lakes	E.C ($\mu S\ cm^{-1}$)	T.S. ($mg\ L^{-1}$)	T.D.S. ($mg\ L^{-1}$)	T.S.S. ($mg\ L^{-1}$)	References
Hanumanantal, Jabalpur	-	300.25-372.25	-	-	Dhamija and Jain, 1995
Barwani pond, M.P.	112-250	-	97-225	300-650	Mahajan and Kanhere,1995
Dal lake, Kashmir	112-275	-	-	-	Sarwar *et al.*, 1996
Saroor Nagar lake, Hyderabad	-	512.2-1892.8	312-1209	174.0-684.8	Paka and Rao, 1997
O. U. campus pond, Hyderabad	-	382-976	244-698	34-326	Paka and Rao, 1997
Banjara lake, Hyderabad	-	200.6-1600.0	168-936	32.6-664.0	Paka and Rao, 1998
Upper lake, Bhopal	230-300	-	150-192	-	Tiwari, 1999
Taudaha lake, Kathmandu	286-411	200-344	-	-	Bhatt *et al.*, 1999
Mariut lake, Egypt	1.1-6.5	-	-	-	Khalil, 2000
Marlimund and Pudumund lake, Ooty	10-220	66-364	10-200	56-234	Sivakumar *et al.*, 2000
Gadchiroli lake, Maharashtra	619.60-625.18	-	408.25-415.80	-	Patil and Tijare, 2001
Rankala lake, Kolhapur	-	121.3-294.0	-	-	Rasool *et al.*, 2003
Padamalaya lake Jalgaon, Maharashtra	502.1-627.1	344.91-370.11	267.55-318.12	45.44-52.31	Patil *et al.*, 2004
Vellayani lake, Thiruvananthapuran, Kerala	76.29-320.50	61.75-338.50	42.5-226.25	44.25-104.75	Radhika *et al.*, 2004

The values of conductivity of waters of different lakes varied from 1.1 to 627.1 μS cm^{-1}. Total solids, total dissolved solids and total suspended solids in different lakes varied from 66.0 to 1892.8, 10.0 to 1209 and 32.6 to 684.8 mg L^{-1}, respectively (Table-2.3). Seasonally, EC, TS, TDS and TSS were reported to be the maximum during summer season and minimum during monsoon or after monsoon seasons (Taudaha lake, Vellayani lake). In Barwani pond, the maximum values of these parameters were in the month of May and minimum in June. Pre-monsoon (summer) maxima and monsoon (rainy) minima of conductivity values might be due to increased rate of evaporation leading to high concentration of salts in summers and dilution due to precipitation in rainy season, respectively (Radhika, *et al.,* 2004). The increased level of TS, TDS, and TSS during pre-monsoon might be because of the evaporation of water and high density of plankton. Shallowness of the lake during pre-monsoon season also made frequent uplifting of loose silt from the bottom, which might also have contributed to the increased concentration of TSS.

2.1.3 Dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD)

Dissolved oxygen is an important parameter which affects chemical as well as biological reactions in an ecosystem. It is essential to the life of fish and other aquatic organisms. Oxygen content is important for direct respiration need of many organisms and affects the solubility and availability of many nutrients and therefore, controls the productivity of aquatic ecosystem (Wetzel, 1983). The factors affecting the oxygen balance

Table 2.4 Dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) in waters of some lakes

Name and location of lakes	DO (mg L^{-1})	BOD (mg L^{-1})	COD (mg L^{-1})	References
Kaptai lake, Bangladesh	6.63-6.65	-	-	Khan and Chowdhary, 1994
Hanumanantal, Jabalpur	6.62-7.87	-	-	Dhamija and Jain, 1995
Barwani pond, M.P.	6.90-8.30	-	-	Mahajan and Kanhere,1995
Saroor Nagar lake, Hyderabad	1.3-15.8	-	-	Paka and Rao, 1997
O. U. campus pond, Hyderabad	2.8-13.6	-	-	Paka and Rao, 1997
Banjara lake, Hyderabad	5.2-20.8	-	-	Paka and Rao, 1998
Taudaha lake, Kathmandu	5.0-10.2	6.5-32.0	-	Bhatt *et al.*, 1999
Mariut lake, Egypt	-	15-182	85-985	Khalil, 2000
Marlimund and Pudumund lake, Ooty	6.4-9.2	<5.0	16-36	Sivakumar *et al.*, 2000
Gadchiroli lake, Maharashtra	5.7-6.1	-	-	Patil and Tijare, 2001
Subhas Sarobar lake, East Calcutta	4.7-8.1	-	-	Saha *et al.*, 2001
Rankala lake, Kolhapur	-	0.45-2.5	62.4-164.0	Rasool *et al.*, 2003
Padamalaya lake Jalgaon, Maharashtra	6.53-6.8	-	2.32.33-282.67	Patil *et al.*, 2004
Naregal tank, Haveri, Karnataka	6.8-9.6	1.2-7.2	68--96	Kudari *et al.*, 2004
Vellayani lake, Thiruvananthapuran, Kerala	4.11-7.11	4.06-21.85	12.8-43.2	Radhika *et al.*, 2004

in water bodies are: input from atmosphere and photosynthesis and output from respiration, decomposition and mineralization of organic matter as well as losses to atmosphere.

Biological oxygen demand (BOD) represents the amount of oxygen required for the microbial decomposition of organic matter in water whereas, chemical oxygen demand (COD) is a reliable parameter in judging the extent of organic pollution and is a measure of oxygen required for complete oxidation of organic matter by a strong oxidant.

The values of DO, BOD and COD of different lakes varied from 1.3 to 20.8, 1.2 to 182.0 and 12.8 to 985 mg L^{-1}, respectively (Table-2.4). The maximum DO in the waters of lakes was found during monsoon season and minimum during summer however, some lakes showed maximum DO during summer season. Tolerance limit of dissolved oxygen is less than 6 mg L^{-1} (Kudesia, 1985). The dissolved oxygen below this limit was found only during summer, which might be due to higher anthropogenic activities. Decomposition of organic matter might also be an important factor in consumption of dissolved oxygen, as more vigorous deposition is likely during warm weather (Bagde and Verma, 1985; Singh and Sahai, 1979). The phenomenon of re-oxygenation of water during monsoon may be due to circulation and mixing by inflow after monsoon rains (Hannan, 1978).

Higher concentration of DO during summer may be attributed to active photosynthesis and luxuriant growth of phytoplankton, which results in the liberation of oxygen. The increase in temperature accelerates photosynthetic oxygen production, which in turn increases the content of dissolved oxygen (Mahajan and Kanhere, 1995).

Reid (1961) pointed out that a rapid and abundant growth of blooms (phytoplanktons) also increase the oxygen content of water during summer.

2.1.4 Cations (NH_4^+, K^+, Na^+, Ca^{2+} and Mg^{2+}) and total hardness (TH)

The main cations present in water samples are ammonium, calcium, magnesium, potassium and sodium. Metals (Ca, Mg, K & Na) do not pose health hazards, but their excessive amounts impart objectionable characteristics to water such as taste, colour and hardness.

The nitrogenous organic matter present in water is degraded biologically with the production of ammonia. The most important source of ammonia in natural water is the decomposition and ammonification of organic matter and also the excreta of some aquatic animals. Though potassium ranks seventh among the elements in the order of abundance, its concentration in most drinking water is trivial. The concentrations of potassium remain quite lower than the sodium, calcium and magnesium in aquatic ecosystems (Trivedy *et al.*, 1987). Although K is found in less quantity yet it is also important in the ecology of blue-green algae (Wetzel, 1966).

Sodium is present in most natural waters from negligible to appreciable concentrations. The salts of sodium are highly soluble in water and impart softness to water. It has importance only with respect to irrigation use of water. However, the excessive amounts of sodium in

Table 2.5 Cations (NH_4^+, K^+, Na^+, Ca^{2+} and Mg^{2+}) and total hardness (TH) in waters of some lakes

Name and location of lakes	NH_4^+ (mg L^{-1})	K^+ (mg L^{-1})	Na^+ (mg L^{-1})	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	TH (mg L^{-1})	References
Kaptai lake, Bangladesh	-	-	-	7.46-8.29	-	-	Khan and Chowdhary, 1994
Hanumanantal, Jabalpur	-	-	-	73.7-127.5	18.75-45.62	92.5-167.5	Dhamija and Jain, 1995
Dal lake, Kashmir	.051-1.97	1-70	4-36	20.2-94.6	-	-	Sarwar *et al.*, 1996
Saroor Nagar lake, Hyderabad	-	-	-	29.94-92.10	8.6-126.1	104.4-586.	Paka and Rao, 1997
O. U. campus pond, Hyderabad	-	-	-	17.2-116.6	3.5-60.4	57.6-382.2	Paka and Rao, 1997
Banjara lake, Hyderabad	-	-	-	10.0-40.3	3.5-35.0	68.0-208.8	Paka and Rao, 1998
Upper lake, Bhopal	-	4.0-5.8	16.17-23.25	36-66	14-86	-	Tiwari, 1999
Taudaha lake, Kathmandu	0.0-0.081	-	-	-	-	-	Bhatt *et al.*, 1999
Mariut lake, Egypt	5.9-28.1	-	-	-	-	-	Khalil, 2000
Marlimund and Pudumund lake, Ooty	-	-	-	0.0-52.0	0.0-0.0	0.0-52.0	Sivakumar *et al.*, 2000
Gadchiroli lake, Maharashtra	-	-	-	61.0-65.2	84.24-88.00	7.25-7.92	Patil and Tijare, 2001
Subhas Sarobar lake,E.Calcutta	-	-	-	-	-	47-72	Saha *et al.*, 2001
Rankala lake, Kolhapur	-	-	-	77-355.45	22.10-30.59	21.66-156.45	Rasool *et al.*, 2003
Padamalaya lake Jalgaon, Maharashtra	-	13.02-14.49	18.23-20.63	29.84-31.97	15.98-16.53	248.21-252.20	Patil *et al.*, 2004
Naregal tank, Karnataka	7.4-10.6	-	-	7.2-20.8	0.486-0.972	20-56	Kudari *et al.*, 2004
Vellayani lake, Thiruvananthapuran, Kerala	-	-	-	-	-	15.50-35.51	Radhika *et al.*, 2004

drinking water are harmful to persons suffering from cardiac, renal and circulatory diseases (Behera *et al.*, 2004).

The presence of Ca in water is mainly due to its passage through or over the deposits of limestone, dolomite, gypsum and other gypsiferous materials (Manivasakam, 1989). The calcium content may range from zero to several hundred mg L^{-1}, depending on the source and treatment of water.

Magnesium is an essential element for human beings and is relatively non-toxic. However, at higher concentrations, magnesium salts have a laxative effect particularly, when it is present as magnesium sulphate. Magnesium salts occur in significant concentration in natural rocks (Behera *et al.*, 2004).

Hardness of water is mainly due to the presence of calcium and magnesium ions, and is an important indication of the toxic effects of poisonous elements (Kaushik and Saksena, 1999). According to Ruttener (1953), the total hardness is the total amount of alkaline earths present without reference to the particular anion to which they are bound.

The content of ammonium nitrogen in different lakes varied from 0.0 to 28.1 mg L^{-1}. The content of K, Na, Ca and Mg varied from 1.0 to 70.0, 4.0 to 65.2, 0.0 to 355.45 and 0.0 to 60.4 mg L^{-1}, respectively whereas the total hardness varied from 0.0 to 586.8 mg L^{-1} (Table-2.5).

Maximum content of cations was generally found during summer and minimum during monsoon and post-monsoon season. In case of Hanumantal, Saroornagar lake and Banjara lake, waters had the maximum Ca and Mg content during monsoon and post-monsoon season.

Waters rich in bicarbonates are also rich in calcium as well. It is due to the conversion of soluble $CaCO_3$ to insoluble calcium bicarbonate in the presence of CO_2. High values of hardness in lakes may be due to addition of calcium and magnesium salts from detergents as they are used for washing and bathing (Radhika *et al.*, 2004). Higher values of hardness in summer might be due to high temperature, which increased concentration of salts by excessive evaporation. The contents released from dead molluscan shells might also increase the concentration of total hardness (Khan and Chowdhary, 1994).

2.1.5 Anions (NO_3^-, PO_4^{2-}, SO_4^{2-} and Cl^-)

Besides $CO_3^{--}$and HCO_3^-, waters generally contain other anions like NO_3^-, PO_4^{2-}, SO_4^{2-} and Cl^-. Nitrate (NO_3^-) is the most highly oxidized form of nitrogen and is the abundant form of inorganic nitrogen in lakes and streams. It is a stable product of aerobic oxidation of nitrogenous organic matter. A limit of 10 mg NO_3^--N L^{-1} has been imposed on drinking water to prevent methaemoglobinemia in infants.

Phosphorus occurs in natural waters and wastewater almost solely as phosphates. Phosphate- phosphorus plays an important role on algal population and acts as a primary limiting factor. The most important anthropogenic sources of phosphates are the discharge of domestic sewage; detergents and agricultural run-off (Trivedy *et al.*, 1987).

Sulphur occurs naturally in water as a result of leaching from gypsum and other common minerals. The sulphate is usually second to carbonate as the principal anion in fresh waters, although chloride sometime surpasses it (Behera *et al.*, 2004). Contamination of water from

Table 2.6 Anions (NO_3^-, PO_4^{3-}, SO_4^{2-} and Cl^-) in waters of some lakes

Name and location of lakes	NO_3^- (mg L^{-1})	PO_4^{3-} (mg L^{-1})	SO_4^{2-} (mg L^{-1})	Cl^- (mg L^{-1})	References
Kaptai lake, Bangladesh	0.030-0.044	0.052-0.053	-	2.69-2.76	Khan and Chowdhary, 1994
Hanumanantal, Jabalpur	-	-	-	58.73-106.46	Dhamija and Jain, 1995
Barwani pond, M.P.	0.15-1.50	0.1-2.2	25.0-67.7	7.2-14.0	Mahajan and Kanhere,1995
Dal lake, Kashmir	0.30-2.69	0.19-6.50	-	17-109	Sarwar *et al.*, 1996
Saroor Nagar lake, Hyderabad	0.0-0.70	0.2-1.8	-	205.8-800.9	Paka and Rao, 1997
O.-U. campus pond, Hyderabad	0.04-0.44	0.0-0.40	-	78.1-357.4	Paka and Rao, 1997
Banjara lake, Hyderabad	0.088-0.443	0.0-0.10	-	46.2-191.4	Paka and Rao, 1998
Upper lake, Bhopal	-	-	-	32-56	Tiwari, 1999
Taudaha lake, Kathmandu	0.015-0.035	0.025-0.053	-	-	Bhatt *et al.*, 1999
Mariut lake, Egypt	0.02-0.60	-	230-610	-	Khalil, 2000
Marlimund and Pudumund lake, Ooty	-	0.0-0.0	-	4.0-35.0	Sivakumar *et al.*, 2000
Gadchiroli lake, Maharashtra	-	-	-	31.87-35.13	Patil and Tijare, 2001
Subhas Sarobar lake, East Calcutta	0.02-7.50	0.23-0.61	-	-	Saha *et al.*, 2001
Rankala lake, Kolhapur	-	5.54-9.5	128.25-229.5	245-699.58	Rasool *et al.*, 2003
Padamalaya lake Jalgaon, Maharashtra	4.61-5.35	0.55-0.65	-	39.59-40.53	Patil *et al.*, 2004
Naregal tank, Haveri, Karnataka	-	0.0-0.4	0.0-10.0	44.02-46.86	Kudari *et al.*, 2004
Vellayani lake, Thiruvananthapuran, Kerala	0.003-0.029	0.012-0.022	-	62.03-275.55	Radhika *et al.*, 2004

domestic sewage can be monitored by chloride assays of the concerned water bodies. This is because human and animal excretions contain an average of 5 g Cl L^{-1}.

The values of NO_3^-, PO_4^{--}, SO_4^{--}, and Cl^- in waters of different lakes varied from 0.0 to 7.5, 0.0 to 9.5, 0.0 to 610 and 2.69 to 800.9 mg L^{-1}, respectively (Table-2.6).

The maximum values of these anions were found during summer and the minimum during monsoon and post-monsoon seasons (Kaptai lake, Hanuman tal, Barwani pond, Saroor Nagar lake, Banjara lake and Vellayani lake). On the other hand, Taudana lake, Subhas sarobar lake and Naregal tank were having the minimum NO_3^- content during summer and maximum during monsoon or winter season.

High concentrations of above parameters during summer might be due to the high anthropogenic activities coupled with setting of particulates at the bottom due to the restricted flow of water by the sluice. In summers, the temperature is raised, which enhanced the release of nutrients from sediments through bacterial growth (Saha *et al.,* 2001).

The low content of nitrate in the water during the active growth of vegetation (summer) may be due to the utilization of nitrate during photosynthesis or due to action of denitrifying bacteria, which are quite active at higher temperature (Mahajan and Kanhere, 1995). The variation in the concentration of phosphate may be associated with photosynthetically induced precipitation and its utilization by autotrophs (Shreenivasa *et al.,* 1999). Higher concentration of nitrates and phosphates during rainy season might be due to enrichment through water received from surface runoff. Sawyer (1966) suggested 0.03 mg L^{-1} of phosphate-phosphorus as critical level and higher concentrations accelerated growth of phytoplankton. An increase in phosphate content is an indicator of eutrophication.

2.3.6 Irrigation parameters

Sodium adsorption ratio and residual sodium carbonate are the important character of assessing the suitability for irrigation water from the point of view of likely sodium hazards.

Tiwari (1999) reported that SAR values of waters of upper lake was within excellent class and it could be safe or suitable for irrigational purpose without any hazards of lake water. Patil *et al.* (2004) also reported that the waters of Padamalaya lake could be used for irrigation on the basis of SAR value.

2.4 Microbial pollution in water

Lakes are notoriously liable to pollution from neighbouring sources of contamination like latrines, urinals, drains, sewage pipes etc. Lake waters are, therefore, health hazards to the community if no sanitation is undertaken. The total microbial counting procedure provides a standardized means of determining the density of aerobic, facultative anaerobes and heterotrophic bacteria in water. Certain bacterial species particularly, *Escherchia coli* and related organisms designated as *coliforms* are the normal inhabitant of the intestine of the human and are constantly present in the faeces. Mahanta, (1984) showed that the presence of *coliform* organism in water was indicator of faecal matter contamination. These organisms live longer in water than intestinal pathogens. *Coliforms* count performed by the most probable number (MPN) method is the most commonly used indicator of water pollution (Ramketa *et al.,* 1992). The presence of bacteria in drinking water causes many bacterial diseases like typhoid, dysentery and cholera (Sollae, 1974).

Kumaresan and Bagavathiraj, (1996) studied total microbial counts and *coliform* counts (MPN) in 27 samples of drinking water of Courtallam and reported that total counts varied from 35 to 188 per ml and MPN varied from 5 to 197 per 100 ml.

Nair and Shrivastava (2003) reported that MPN in waters of upper lake through 40 years varied from 193 (in 1960) to >10000 (in 2000) per 100 ml.

2.5 Heavy metal pollution in water

Heavy metals occur at very low levels in almost all natural waters due to their presence in geo-chemical sources. Some of them (Fe, Cu, Zn, Ni, Co, Mn) are essential nutrients for aquatic life. At higher levels, they are toxic. In India, majority of water bodies are invariably polluted by industrial and domestic wastes. Some of the heavy metals are essential to humans, eg. Co, Cu, Mo etc, but large quantities of them may cause physiological disorders and many of them are quite serious (Trivedy and Goel, 1986). Therefore, monitoring of water courses becomes an essential part of water quality management. The measurements and characterization of heavy metals in waters are necessary to understand their distribution and pathways in the ecosystem and to assess the

Table 2.7. Heavy metal pollution (mg L^{-1}) in some lakes

Name and location of lakes	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb	Reference
Lower lake, Bhopal	-	-	-	-	0.012-0.181	0.058-0.157	0.002-0.075	0.005-0.156	Jain and Salman, 1995
Fresh water pond, Coimbatore	-	1.1	3.1	-	2.1	1.2	1.05	-	Francis *et al.*, 1997
Motijheel	0.020-0.038	0.009-0.016	-	0.0-0.003	0.024-0.034	0.065-0.120	0.010-0.019	0.003-0.009	Kaushik *et al.*, 1999
Surajkund	0.030-0.048	0.010-0.016	-	0.0-0.004	0.017-0.026	0.079-0.116	0.012-0.018	0.002-0.009	
Ranital	0.028-0.042	0.009-0.016	-	0.0-0.003	0.018-0.028	0.065-0.116	0.009-0.015	0.003-0.009	
Saroor Nagar lake and Banjara lake, Hyderabad	-	-	0.0-0.6	-	-	-	-	-	Paka and Rao, 1997,1998
Mariut lake, Egypt	0.10-0.52	-	3.5-10.2	0.05-0.46	0.12-0.66	0.08-0.30	-	0.03-0.32	Khalil, 2000
Selvachintamani lake	0.387	1.257	8.08	0.007	0.177	0.493	0.01	0.375	Mohanraj *et al.*, 2000
Singanallur lake	0.052	0.255	0.520	0.023	0.044	0.095	0.001	0.026	
Ukkadam lake	0.030	0.055	1.425	0.006	0.018	0.034	0.001	0.011	
Perur lake	0.043	0.071	1.735	0.009	0.030	0.053	0.001	0.005	
Valankulam lake	0.049	0.346	0.640	0.025	0.025	0.100	0.002	0.026	
Ammankulam lake	0.042	0.064	3.285	0.012	0.044	0.101	0.001	0.005	
Selvampatti lake	0.035	0.083	3.405	0.011	0.026	0.053	0.0	0.016	
Kumaraswamy lake	0.062	0.055	1.165	0.006	0.028	0.069	0.0	0.015	
Padamalaya lake Jalgaon, Maharashtra	-	-	-	-	5.1-5.2	2.87-3.03	-	-	Patil *et al.*, 2004

impact of their discharge into the environment (Ingole and Dhaktode, 1990).

Chromium (Cr)

Chromium salts impart colour to water. The salts of trivalent chromium are physiologically not harmful. However, the large doses of hexavalent chromium salts lead to corrosive effects in the intestinal tract and to nephritis (Manivasakam, 1989). It is one of the highly toxic metals responsible for various health hazards (Forstner, 1976; Kudesia, 1989; Forstner and Wittmann, 1981).

Chromium is hazardous and creates complication in the utilization of other nutrients by plant (Khan and Khan, 1985). The chromium content in natural waters is usually very small. Elevated concentrations can result from mining and industrial processes (Datar and Vashishth, 1990). The values of chromium in waters of various lakes varied from 0.02 to 0.387 mg L^{-1}. Lower lake of Bhopal was found to contain the maximum value of chromium in summer and minimum in winter, whereas Motijheel, Surajtal and Ranital of Gwalior region were containing the maximum chromium content in rainy season and the minimum in summer season.

Manganese (Mn)

Manganese is found in all animals as a cofactor in a large number of enzymes. It plays a role in proper functioning of flavoproteins and in the synthesis of sulfated mucopolysaccharides, cholestrol, haemoglobin and in many other important metabolic processes (WHO, 1988).

Manganese content in waters of various lakes varied from 0.009 to 1.257 mg L^{-1}. Motijheel, Surajkund and Ranital contained the maximum Mn content during rainy season and the minimum during summer.

Iron (Fe)

Iron usually exists in natural water both in ferric and ferrous forms. Usually the ferric form is predominant in most of the natural waters. Iron exists in the soluble state under reducing conditions. On exposure to air or on addition of oxidants, soluble ferrous iron is oxidized to insoluble hydrated ferric oxides rapidly by dissolved oxygen at neutral pH conditions of water, iron gets hydrolysed and forms insoluble hydroxides. According to Rao (1970), acidic waters support greater quantities of iron. The oxides and hydroxides of iron and manganese constitute a significant sink of heavy metals in aquatic system (Jenne, 1976). Iron was found to be harmful to the fishes even in low concentrations as ferric hydroxide (Metelev *et al.* 1971).

Iron content in waters of various lakes varied from nil to 8.08 mg L^{-1}. The maximum iron content has been reported during summer season while the minimum during monsoon season or post monsoon seasons (Saroor Nagar lake, O.U ponds, Banjara lake). Some lakes were having the maximum iron content during monsoon and the minimum during summer (Motijheel, Surajkund and Ranital). Low contents of iron in summer resulted due to the precipitation of ferric sulfate.

Nickel (Ni)

Nickel is an important non-ferrous metal closely related to iron and cobalt. Generally nickel does not occur in natural waters. It is relatively non-toxic elements at lower level, but higher amount (>30 mg) may cause changes in muscle, brain, lungs, liver and kidney and can also cause cancer (Ramteke and Moghe, 1986).

Nickel contents of various lakes varied from nil to 0.460 mg L^{-1}. Mariut lake of Egypt had higher content of nickel (0.46 mg L^{-1}). Among Indian lakes, the nickel content in waters is generally very low. Motijheel, Surajkund, and Ranital of Gwalior region had nickel content below detection limit *i e* 0.001 mg L^{-1} in summer season but during rainy season it was found to vary from 0.003 to 0.004 mg L^{-1}.

Copper (Cu)

Copper salts occur only in trace amounts up to 0.05 mg L^{-1} in natural surface water. Copper occurs as native metals and in sulfide ores in nature. Copper salts are used in water supply systems to control biological growths in reservoirs and distribution pipes and to catalyse the oxidation of manganese. Corrosion of Cu containing alloys in pipe-fittings may introduce measurable amounts of Cu into the water in pipe system. Copper poisoning leads to toxic effects like ptyalism, nausia, hematuria, convulsions and death (Prasad, 1978).

Copper content in waters of various lakes has been reported to vary from 0.012 to 0.181 mg L^{-1}. Lower lake of Bhopal was found to contain the maximum Cu content during summer and the minimum during winter season whereas, in waters of Motijheel, Surajkund and Ranital, the content was the maximum during rainy season and minimum during summer season.

Zinc (Zn)

Zinc has no known adverse physiological effects upon human beings. In fact, it is an essential element in plant and human nutrition. From aesthetic point of view, however, high concentrations (>5 mg L^{-1}) of zinc in domestic waters are undesirable. Zinc is commonly found in small quantities in domestic water supplies. A relatively higher concentration of Zn may be toxic to aquatic life (Kothandaraman and Viswanathan, 1986).

Zinc content in waters of various lakes has been reported to vary from 0.034 to 0.157 mg L^{-1}. Lower lake of Bhopal had the maximum Zn content during summer and the minimum during winter whereas, Motijheel, Surajkund and Ranital of Gwalior region were having the maximum values during rainy season and the minimum during summer season.

Cadmium (Cd)

Cadmium is a bluish white metal. Cadmium is used as fungicides, insecticides, nematicides, polymerization catalyst, pigments etc. and also occurs as a contaminant of super phosphate fertilizers. Cadmium has very high toxic potential and only trace quantities of Cd are known to cause adverse renal arterial changes in human kidneys. Cadmium tends to concentrate in liver, kidneys, pancreas and thyroid of humans and animals. Once it enters the body, it is likely to remain for long time (Nayak and Sawant, 1994; Forstner, 1976; Kudesia, 1989). Cadmium toxicity (50 mg L^{-1}) causes vomiting, diarrhoea, abdominal pain, loss of bone, deformation etc. (Chatterjee, 1984).

The content of Cd in waters of various lakes has been reported to vary from nil to 0.075 mg L^{-1}. In general, the concentration of Cd is comparatively lower than other heavy metals. Lower lakes of Bhopal had the highest Cd content during summer and the minimum during monsoon season. Motijheel, Surajkund and Ranital of Gwalior region were having the maximum Cd content during rainy season and the minimum during summer season.

Lead (Pb)

Lead is generally not found in natural water supply. Its occurrence may be due to the corrosion reactions and wastes contamination. Pollution due to lead is mainly attributed to the industrial effluents, coal combustion products and petroleum washings from various mechanical workshops, garages as lead is being used as antiknocking compounds in petroleum (Katariya, 1994). The contamination of Pb is also due to domestic sewage discharge (Harison and Laxan, 1984). Automobile exhaust also adds considerable amounts of lead particles to the water (Pophali *et. al.,* 1990) so also the traffic of diesel and petrol vehicles (Agrawal *et al.,* 1978). Lead is classified as highly toxic element in nature (Forstner, 1976; Kudesia, 1989). Lead in high dose has been recognized as a cumulative type general metabolic poison (Suess, 1982).

The content of Pb in waters of various lakes has been reported to vary from 0.003 to 0.156 mg L^{-1}. Lower lakes of Bhopal contained the maximum lead during summer and the minimum during monsoon season. Motijheel, Surajkund and Ranital of Gwalior region contained the maximum values of lead during rainy season and minimum during summer season.

2.6 Heavy metals in sediments

Sediments play an important role in governing the chemical characteristics of water. Metals tend to accumulate in the environment especially, with bottom sediments of rivers and lakes due to their association. with organic and inorganic matter through processes of adsorption, complex formation and chemical precipition (Forstner and Prosi, 1979). According to Zulling (1956), sediments are important indicators of anthropogenic activity. Sediments are the effective sink for heavy metals.

Radwan *et al.* (1990) reported that Fe, Zn and Mn were the most abundant heavy metals in sediments of a lake ecosystem of eastern Poland. Rognerud and Fjeld (1993) studied the content of heavy metals in sediment of 210 lakes in Norway and reported that Pb was the most widely distributed heavy metals in almost all lakes.

Saeki *et al.* (1993) studied heavy metal accumulation in a semi-enclosed hyper-eutrophic system, Lake Teganuma, Japan and reported that except Fe, the vertical distribution of heavy metals showed the highest concentration in the surface 10 cm layer and decreased with sediment depth. The higher concentration in the upper layer was due to the increase in the non-residual fractions.

Jain and Salman (1995) reported that the concentration of Cu, Zn, Pb and Cd in highly eutrophic lake sediment varied from 45-95 ppm, 200-360 ppm, 65-110ppm and 10-20 ppm, respectively. The maximum concentration of these elements was observed during summer and the minimum during monsoon season. Heavy metals concentration increased with the increase in pH.

Ali *et al.* (1999) studied the heavy metal pollution in Nainital Lake and reported that concentrations of Fe, Pb and Ni in sediments were higher than the maximum permissible limits.

Boyle and Briks (1999) suggested that sediment-water partitioning model has an important contribution to field scale studies of sediment borne heavy metals and has important implications for palaeolimnological evaluations of heavy metal deposition.

Ikem *et al.* (2003) studied heavy metal load (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Vd and Zn) in sediment of Tuskegee Lake and found that the metals were distributed in both the non-residual and residual phases except for Ni which was found to concentrate in the residual fraction.

Lindau and Hossner (1982) studied sediment fraction of Cu, Ni, Zn, Cr, Mn and Fe in three natural marshes and reported that heavy metal concentrations in the exchangeable and water-soluble fraction were low compared to other fractions. Approximately 30% of the total Cu, Ni and Zn was associated with the organic matter fraction.

MATERIALS & METHODS

Chapter 3

Materials and Methods

All investigations pertaining to the present study were carried out at Micronutrient Laboratory, Department of Soil Science, G. B. Pant University of Agriculture and Technology, Pantnagar. The details of the materials used and methods followed during the course of investigation are presented herein:

3.1 Sources of Chemicals and glassware

3.2 Instruments used

3.3 Description of sampling sites

3.3.1 General description

3.3.2 Climate

3.3.3 Vegetation

3.4 Collection of water and sediment samples

3.5 Chemical analysis of water

3.5.1 pH

3.5.2 Electrical conductivity

3.5.3 Dissolved oxygen and biological oxygen demand

3.5.4 Chemical oxygen demand

3.5.5 Nitrogen (NH_4^+- and NO_3^--N)

3.5.6 Phosphorus (PO_4^{3-})

3.5.7 Potassium (K^+)

3.5.8 Sulphur (SO_4^{2-})

3.5.9 Calcium (Ca^{2+}) and magnesium (Mg^{2+}) and total hardness (TH)

3.5.10 Sodium (Na^{+})

3.5.11 Chloride (Cl^{-})

3.5.12 Carbonate (CO_3^{2-}), bicarbonate (HCO_3^{-}) and total alkalinity (TA)

3.5.13 Sodium adsorption ratio (SAR)

3.5.14 Residual Sodium Carbonate (RSC)

3.6 Microbiological analysis of water

3.7 Analysis of Heavy metal concentration in the water

3.8 Physico-chemical analysis of sediment

3.8.1 Mechanical analysis

3.8.2 pH

3.8.3 Electrical conductivity

3.8.4 Total and readily oxidised carbon

3.8.5 Calcium carbonate content ($CaCO_3$)

3.8.6 Chemical fractions of metals

3.9 Statistical Analysis

3.1 Sources of Chemicals and glassware

All the chemicals used in the study were of analytical grade procurred from M/S Merck (India) Ltd. and Qualigen. Distilled water was prepared using a Quartz distillation set. The glasswares used in the study were of class 'A' specification supplied by M/S Borosil, Bombay.

3.2 Instruments used

Atomic absorption spectrophotometer: GBC-Avanta-M (Australia)

UV/VIS spectrophotometer	: ECIL, Hyderabad
Flamephotometer	: Elico CM 180
Centrifuge	: R-24, Remi Instruments (India)
Orbital shaker incubator	: Remi Instruments (India)
Electronic digital balance	: Sartorius
pH meter	: Century make
E. C. meter	: Systronics

3.3 Description of sampling sites

3.3.1 General description of lakes

For this study, seven natural lakes of Nainital District, Uttaranchal namely Bhimtal, Naukuchiatal, Sitatal, Ramtal, Hanumantal, Punatal and Nainital (Fig. 1) were selected. Sitatal, Ramtal and Hanumantal are collectively referred as Sattal. General description of these lakes is as under:

Bhimtal. Bhimtal, named after one of the Pandava brothers, 'Bhim', is located at 1346 m above msl. It lies at a latitude of 29^0 21' N and longitude 79^0 24' E. The shape of lake is roughly 'C' type. This is the biggest of all the aforesaid lakes with 0.478 sq. km lake surface area and 10.77 sq. km total catchment area. The average lake length is about 1701 m with average width of 457 m. Its depth varies from 2 to 18 m. The total capacity of lake is about 4.61 Mm^3. The total area is 5875 (2001 interim census report). The lake water is cool and provides

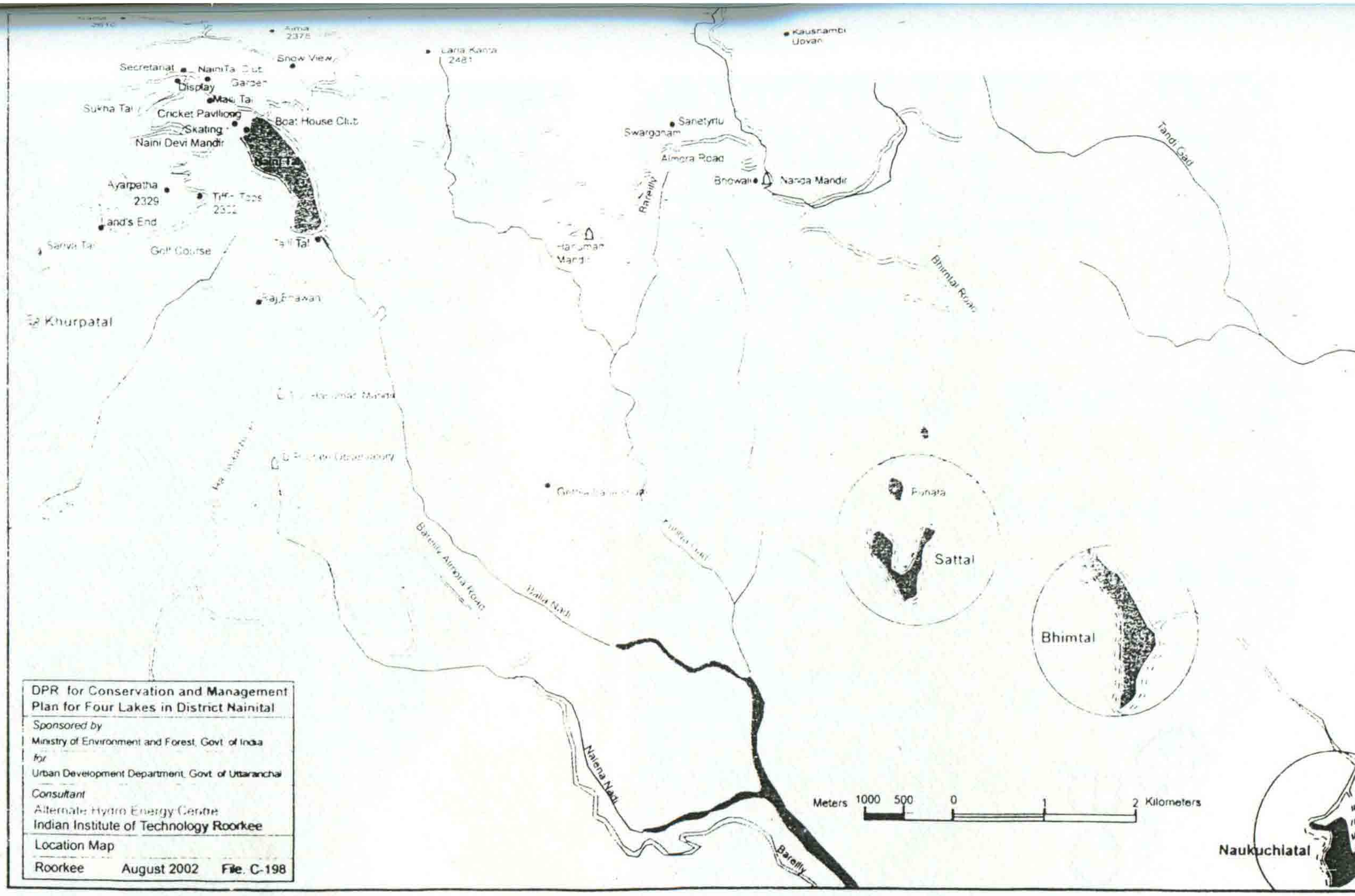

Fig. 3.1 Location map showing various lakes in District Nainital

Plate I : View of Bhimtal

Plate II : View of Naukuchiatal

unmatched comfort and peace to visitors. Tourists enjoy swimming and boating in this beautiful emerald lake (Plate I).

Naukuchiatal. Naukuchiatal is located at 1300 m above msl with surface and total catchment areas as 0.318 and 1.032 sq. km^2, respectively. It lies at a latitude of 29^0 25' N and longitude 79^0 20' E. The average length of lake is 950 m with width of 691 m. Its depth varies from 2.13 to 36.5 m. The total capacity of lake is about 7.37 Mm^3. The shape of lake is roughly 'B' type. According to 2001 census report, the population of 14 villages in the catchment is 3722. This beautiful lake with its nine corners is a paradise for anglers and swimmers and a heaven both for local and migratory birds as well as for moths, butterflies and beetles. A lotus pond on one corner of the lake provides rare beauty and charm to the visitors (Plate II).

Ramtal, Sitatal and Hanumantal (Sattal). Sattal named after the epic protagonists, Ram, Sita, Laxman and Hanuman is located at 1280 m above msl. It lies at a latitude of 29^0 21' N and longitude 79^0 32' E. The average length and width of lake is 900 m and 165 m, respectively and depth varies from 2-10 m. The surface area of the lake is 0.182 sq. km and has total catchment area of 5.69 sq. km. It's total capacity is 0.89 Mm^3. The shape of lake is roughly 'S' type. It is supreme in beauty and ideal for picnics, bird watching and angling, swimming and boating. The total population of five villages in the catchment area is 3307 (2001 census) (Plate III & IV).

Punatal (Garuntal). Punatal is located just near Sattal. It is the smallest lake among all lakes selected for study. It is surrounded by

Plate III : View of Sitatal

Plate IV : View of Hanumatal

lush green vegetation. It is almost untouched by tourists. The shape of lake is about oval type (Plate 5).

Nainital. The Nainital lake is a kidney shaped water body which lies between latitudes 29^0 30' 30" N to 29^0 23' 30" N and longitude 79^0 27' 30". It is located at an altitude of 1938 m on the southern extremity of lesser Himalayas. The maximum length of lake is 1423 m; the width varies between 423 m to 250 m. The maximum depth of the lake is 27.3 m and mean depth is 18.52 m. The surface area is 0.463 km^2, while the volume is 8.58 Mm^3 and the shoreline is 3458 m. The lake is divided into two sub-basins, Mallital and Tallital (Plate 6).

3.3.2 Climate

Nainital hills experience humid and subtropical climate. The area is cold in winters and pleasant in summers. The valley receives moderate to heavy snowfall (200-600 mm) during winters and temperature drops below the freezing point. The average summer temperature ranges from 20 ^{0}C to 30 ^{0}C. The average annual rainfall ranges from 2000 to 2500 mm at different places.

3.3.3 Vegetation

The watershed of Nainital lake region is characterized by forest and vegetation cover in dense clusters. The lake basin encloses fairly dense cover and vegetation mainly of *Quercus incana* and *Q. dilatata* oak forest, *Cupressus torulosa, Cedrus deodra, Aesculus indica, Fraxinus floribunda, Platenus orientales, Cornus macrophylla* and *Populus ciliate*. The shrubs' *Daphna papyracea, Berberis astica, Rubus laciocarpus* and *Hypercum ceranaum* are also developed in the area.

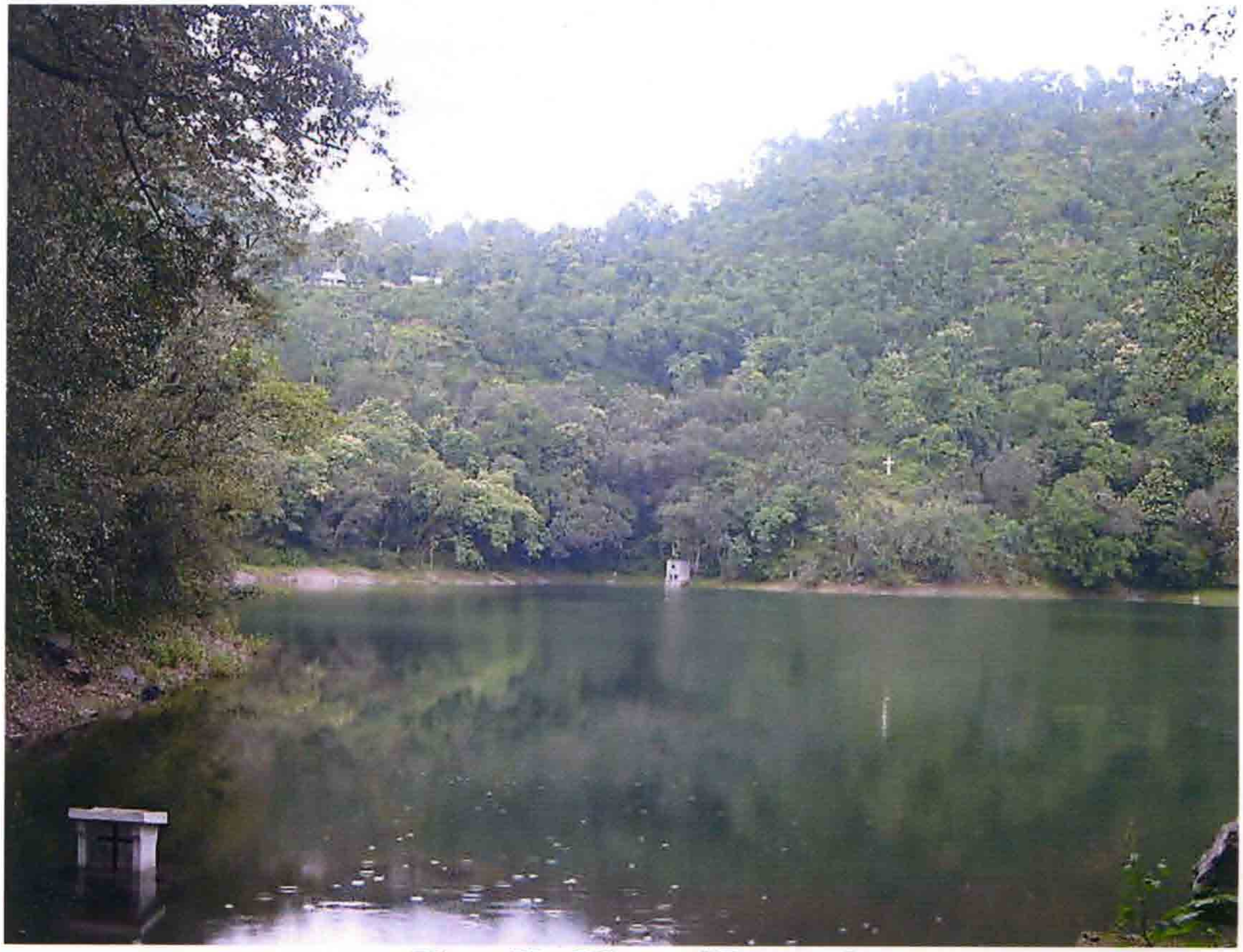
Plate V : View of Punatal


Plate VI : View of Nainital

Some deciduous plants shed their foliage during autumn adding nutrients to the lake.

3.4 Collection of samples

3.4.1 Water. The water samples were collected from Bhim Tal, Naukuchia Tal, Punna Tal, Sita Tal, Ram Tal, Hanuman Tal and Naini Tal of Nainital District in Uttaranchal in four seasons viz., summer (June), autumn (September), winter (December) and spring (March) during 2003-04 and 2004-05. Samples were collected in the acid washed plastic cans following the standard procedure. The samples were brought to the laboratory on the same day and were analyzed for pH and EC. Thereafter, they were preserved at 4°C for further analysis.

3.4.2 Sediments. The sediment samples were also collected from lakes in summer-2004 and summer-2005. The samples were sieved by a 2 mm sieve on the same day and analyzed for pH and EC. Thereafter, they were preserved at 4°C for further analysis.

3.5 Chemical analysis of water

Nitrogen, phosphorus and potassium and other cations and anions in the samples were determined as per procedure outlined by Tandon (2001) and APHA (1998).

3.5.1 pH

It was determined by using a digital pH meter having a combined glass electrode.

3.5.2 Electrical conductivity

It was determined using an Electrical conductivity meter (Systronics) and expressed in mS cm^{-1} at 25 ^0C.

3.5.3 Dissolved oxygen (DO) and Biological oxygen demand (BOD)

The dissolved oxygen and biological oxygen demand were determined by Modified Winkler's method. At each sample site, water sample was filled in each of two 300 ml capacity B.O.D. bottles. One was used to measure initial DO in the sample and second was kept for three days' incubation at 27^{0}C. Two ml of manganous sulphate and 2 ml of alkali-iodide-azide solution were added in the first bottle. The bottle was stoppered without entrapment of air and mixed by inverting the bottle atleast about 10 times. After settling of the precipitate, the stopper was removed carefully and two ml of conc. H_2SO_4 was added. The bottle was stoppered and mixed thoroughly until dissolution was completed. Two hundred and four ml of the solution from the bottle (which corresponded to 200 ml of the original sample) was measured into a conical flask of 500 ml capacity. The contents were then titrated with 0.025 *N* sodium thiosulphate solution using starch as indicator.

1.0 ml of 0.025 *N* $Na_2S_2O_3 \equiv$ 200 μg DO

D.O. (mg L^{-1}) = Total number of ml 0.025 *N* $Na_2S_2O_3$ used

This initial DO was recorded as DO_1.

After three days' incubation, DO was measured in all bottles and recorded as DO_3.

Thus, BOD_3 (mg L^{-1}) = DO_1-DO_3

3.5.4 Chemical oxygen demand (COD)

Fifty ml of the water sample was taken in a round bottom reflux flask and then mercuric sulphate was added to it to maintain chloride and mercuric sulphate in ratio of 1:10. Ten ml of 0.25 *N* $K_2Cr_2O_7$ was added and then slowly 30 ml sulfuric acid silver sulphate reagent was added and mix well. The contents of the flask were refluxed for 2 hours. After the flask had cooled, the contents were transferred to a 250 ml Erlenmeyer flask and 50 ml distilled water was added in to it and then 2-3 drops of ferroin indicator was added. The content was then titrated against 1.0 *N* ferrous ammonium sulphate solution. The point at which the colour changed from blue green to red brown was noted as the end point. This procedure was repeated with a blank (distilled water) also.

$$\text{COD (mg L}^{-1}) = \frac{(\text{B} - \text{T}) \times \text{N} \times 1000 \times 8}{\text{Volume of sample (ml)}}$$

Where, T = volume of titrant (FAS) used against sample (ml)

B = volume of titrant (FAS) used against blank (ml)

N = normality of titrant (FAS) (.025)

8 = equivalent weight of oxygen

3.5.5 Nitrogen (NH_4^+- and NO_3^--N)

NH_4^+-N

A 50 ml aliquot of water sample was taken into the distillation flask. A 20 ml of 4 % boric acid solution containing mixed indicator was taken into another 150 ml conical flask and kept below the condenser tube such that the tube end dipped into the solution. Now 10 ml of 10

M NaOH was added into the distillation flask and distillation was started. The distillation was continued till the volume of distillate became 50 ml. The distillate was then titrated with 0.02 *N* H_2SO_4 till the wine red colour reappeared. A blank was also run simultaneously.

$$NH_4^+ - N\,(mg\,L^{-1}) = \frac{(A - B) \times 280}{\text{volume of sample (ml)}}$$

Where,

A = volume of H_2SO_4 used for sample (ml)

B = volume of H_2SO_4 used for blank (ml)

NO_3^--N

A fresh sample (50 ml) was taken into the distillation flask and 0.2g Devarda's alloy was added and same procedure was followed as mentioned for NH_4^+-N determination. The distillate provided the concentration of both NH_4^+ as well as NO_3^--N in water.

NO_3^--N (mg L^{-1}) = (NH_4^+-N + NO_3—N) - NH_4^+-N

3.5.6 Phosphorus (PO_4^{3-})

Phosphorous was determined by ascorbic acid method (Murphy and Riley, 1962). A 10 ml of water sample was taken in a 25 ml volumetric flask and 1 drop 2, 4 dinitrophenol indicator was added into it. If yellow colour appears then, 0.5 *N* H_2SO_4 solution was added drop by drop until the colour disappeared. Now 10 ml of reagent B (5.28 g ascorbic acid in reagent-A, containing 6 g ammonium molybdate + 0.146 g antimony-potassium tartarate + 500 ml of 5 *N* H_2SO_4 + distilled water) was added and the volume was made 25 ml with distilled water and after 10 minutes absorbance was measured at 882 nm on a spectrophotometer. A calibration curve was prepared from the standard solution in the range of (0 to 2 mg P L^{-1}). A calibration curve was drawn plotting absorbance vs. phosphate concentration. The concentration of P in water was calculated from the calibration curve.

mg P L^{-1} = mg P from calibration curve x dilution factor

3.5.7 Potassium (K^+)

Potassium in water was determined by flame photometry. A calibration curve was prepared in the range of 0 to 100 mg K L^{-1}. Potassium concentration was determined from the calibration curve.

mg K L^{-1} = mg K from std. curve x dilution factor

3.5.8 Sulphur (SO_4^{2-})

Turbidimetric method was used to determine the SO_4^{2-} content in water samples. A 5 ml aliquot of water sample was taken in 25 ml volumetric flask and 10 ml of sodium acetate- acetic acid buffer was added to it. One ml of gum acacia solution (0.25%) and 1 g of $BaCl_2$ crystals were added and the contents were mixed. The volume was diluted with distilled water and made upto mark. The turbidity was measured at 420 nm on a spectrophotometer. The shaking period and turbidity measurements were kept constant for all samples.

A calibration curve was drawn between absorbance and known concentrations (0, 1, 2, 3, 4 and 5 mg L^{-1}) of sulphate-S. The sulfate concentration in sample was estimated with the help of the calibration curve.

3.5.7 Calcium (Ca^{2+}), magnesium (Mg^{2+}) and total hardness (TH)

The concentrations of Ca^{+2} and Mg^{+2} in water samples were determined by complexometric titration method as described by Tandon (2001).

For estimation of calcium, 5 ml of sample was taken in a conical flask and diluted by adding 25 ml of distilled water. Now 5 ml of 4 *N* NaOH and 25 mg of ammonium purpurate (murexide) powder were added. The sample was then titrated with standardized 0.01 *N* EDTA solution (Versenate soultion) till the colour changed to purple. A blank was also run simultaneously. As the colour change was not spontaneous, a blank sample was kept for reference to locate the end point more accurately. The solution of EDTA was standardized with 0.01 *N* Ca solution.

For estimation of Ca plus Mg, a 5 ml water sample was taken in a flask and diluted by adding 25 ml of distilled water. One ml of NH_4Cl + NH_4OH buffer (pH 10) and 3-4 drops of Eriochrome Black-T indicator were added to the flask. A wine red colour appeared. The solution was titrated against 0.01 *N* EDTA to sea blue color end point.

Total hardness of water (mg equivalent $CaCO_3$ L^{-1})

$$= Ca^{2+} \times 2.497 + Mg^{2+} \times 4.167$$

Where, Ca^{2+} and Mg^{2+} in mg L^{-1}.

3.5.8 Sodium (Na^+)

Sodium in water samples was analyzed by flame photometry. Working standards of Na were prepared as 0, 1.0, 2.5, 5.0, 7.5 and

10.0 mg L^{-1}. Flame photometer was adjusted 0 with distilled water and 100 reading was adjusted with 10 mg L^{-1} Na solution.

mg Na L^{-1} = mg Na from standard curve x dilution factor.

3.5.11 Chloride (Cl^-)

Mohr's titration method was followed for the estimation of chloride concentration in water. A 5 ml sample was taken in a conical flask and diluted to 100 ml with distilled water. One ml of K_2CrO_4 indicator solution (50 g K_2CrO_4 / 1 L D.W.) was added into the flask and the sample was titrated with 0.0141 *N* $AgNO_3$ to a pinkish yellow end point. The titrating solution of $AgNO_3$ was standardized with 0.0141 *N* NaCl. A blank was also run following the titration method outlined above.

3.5.12 Carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and alkalinity

The estimation is based on simple acid-base titration using different indicators which work in alkaline pH range (above 8.2) or in acidic range (below 6.0).

A 10 ml water sample was taken in a conical flask and diluted by adding about 25 ml of distilled water. Now 2-3 drops of phenolphthalein indicator (0.25%) was added to it. If the red colour appears, it was titrated against 0.01 *N* H_2SO_4 till red colour disappeared. The volume of acid consumed was recorded as 'A'.

Now 2-3 drops of methyl orange indicator (0.5%) was added to the colorless solution and the sample was again titrated till the yellow colour changed to rosy red. The volume of acid consumed was recorded as 'B'.

Carbonates (me L^{-1}) = 4A

Carbonates (mg L^{-1}) = Carbonates (me L^{-1}) × 30

Bicarbonates (me L^{-1}) = 2(B-A)

Bicarbonates (mg L^{-1}) = Bicarbonates (me L^{-1}) × 61

Alkalinity (mg L^{-1}) = Carbonates (mg L^{-1}) + bicarbonates (mg L^{-1})

3.5.13 Sodium adsorption ratio (SAR)

Sodium absorption ratio (SAR) value for each water sample was calculated using the following formula:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Where, concentration of cations was in meq L^{-1}.

3.5.14 Residual Sodium Carbonate (RSC)

It was calculated by using the following formula:

RSC (me L^{-1}) = (CO_3^{2-} + HCO_3^{-}) – (Ca^{2+} + Mg^{2+})

Where, concentrations of both cations and anions were in me L^{-1}.

3.5 Microbiological analysis of water

Total bacterial count

For total bacterial count of water, serial dilution agar plating method was followed. One ml of water sample was taken and serial dilutions were prepared and appropriate dilutions were plated on different selective medium i.e. Nutrient Agar Medium. The plates were incubated at 37 ^{0}C for 24-48 hours. From appropriate dilution only those plates were selected which contained colonies in the range of 30-300 Plate counts were made at 48 h using a colony counter.

$$\text{Number of bacteria per ml} = \frac{\text{Number of colonies} \times \text{Dilution factor}}{\text{Volume of sample (ml)}}$$

Most probable number (MPN)

For each sample, three test tubes containing 10 ml of double strength lactose broth with Durham's tube and 6 test tubes containing single strength lactose broth with Durhum's tubes was sterilized. The collected water samples was inoculated in each test tubes i.e. 10 ml into each of three tubes containing double strength lactose broth, 1 ml into each of three single strength lactose broth tubes and 0.1 ml was inoculated into rest three tubes containing 5 ml single strength lactose broth. All test tubes were kept in the incubator at 37 ^{0}C for 24 to 48 h. After inoculation, all the tubes were observed for the presence of acid and gas. The production of acid and gas indicate the presence of Coliforms and thus, test is positive. The number of positive and negative tubes was matched with standard McCrady Chart and accordingly MPN was calculated.

3.6 Heavy metal concentration in the water

Analysis of heavy metals in waters was done using 10 times concentrated sample. A measured aliquot volume of 10 ml sample was transferred to a beaker and 2 ml of 6 *N* HCl was added to it. The beaker was covered with a ribbed watch glass. It was gently boiled and evaporated on a hot plate to approximately 2 ml. Again, a fresh volume of 10 ml acidified water was added and evaporation was done. This procedure was repeated 25 times and the final volume was reduced to 2-3 ml. The beaker walls and watch glass cover were washed with 6N HCl and filtered into a 25 ml volumetric flask. This solution was used for estimation of Fe, Cu, Mn, Zn, Ni, Pb, Cd and Cr using Atomic Absorption Spectrophotometer (GBC: Avanta-M) as per procedure described in APHA (1998).

3.7 Physico-chemical analysis of sediment

Sediment samples were dried in shade and sieved through a 2 mm sieve. Sediment samples were analyzed for some properties:

3.8.1 Mechanical analysis

Mechanical analysis of sediments was done by Bouyoucos hydrometer method (Bouyoucos, 1927). A 50 g oven dry sediments sample was taken in 1 L beaker. The sample was moistened by 10 ml water and 20 ml H_2O_2 was added. The sample was left for overnight. Next morning, the beaker was kept on hot plate and stirred with glass rod to avoid the over flow of froth. Again 10 ml of H_2O_2 added and digestion was continued. Addition of H_2O_2 was done until frothing was completely stopped. After H_2O_2 treatment, sample was diluted with water (50-100 ml). Hundred ml of 5% calgon solution was added to sample and placed on shaker for few hours. Thereafter, the contents were transferred quantitatively to 1000 ml graduated cylinder. The cylinder was filled with water making the level of suspension up to 1000 ml mark. Mixing of soil water suspension was done by turning the cylinder up side down. After thorough mixing of the content, the hydrometer was suspended in the suspension. The content of silt+clay was estimated from the first hydrometer reading (at 40 second) and the content of clay was estimated from second hydrometer reading (at 2 hours).

Calculation

$$\% \text{Silt} + \text{Clay} = \frac{R_1 \times 100}{\text{Weight of ovendry soil (g)}}$$

$$\% \text{ Clay} = \frac{R_2 \times 100}{\text{Weight of ovendry soil(g)}}$$

% Silt = % Silt + Clay - % Clay

% Sand = 100 - % Silt + Clay

3.8.2 Sediment pH

Sediment pH was measured in 1: 2 sediment water suspension using pH meter (Jackson, 1973).

3.8.3 Electrical conductivity

The electrical conductivity of sediments was determined in 1:2 sediment water- suspension with electrical conductivity meter and expressed in dS m^{-1} (deci Siemens $meter^{-1}$) at 25^0C.

3.8.4 Total and Readily oxidisable carbon

Total carbon

Total carbon in lake sediments was analysed by adopting the method outlined by Page *et al.* (1982).

A 2 g oven dry sediment samples was taken in a round bottom flask. Twenty ml 1 *N* $K_2Cr_2O_7$ + 3 ml water + 25 ml digestion acid (600 ml H_2SO_4 + 400 ml 85% H_3PO_4) were added to the flask. The flask was attached to the condenser and boiling was done for 10 minutes. The contents were cooled and titrated with 0.5 *N* ferrous ammonium sulfate

(FAS) using ferroin indicator. A blank was also run following same procedure. Total soil organic carbon was calculated as given below:

$$\text{Total carbon (\%)} = \frac{(B - S) \times N \text{ of FAS} \times \text{meq. of C}}{\text{Weight of soil sample (g)}} \times 100$$

where,

B = volume of $K_2Cr_2O_7$ used used for titration of blank

S = volume of ferrous ammonium sulfate used for titration of sample

Milliequivalent weight of carbon = 0.003

$$N \text{ of ferrous ammonium sulfate (FAS)} = \frac{\text{Volume of 1 N } K_2Cr_2O_7}{\text{Blank titre}}$$

100 = percentage conversion factor

Readily oxidisable carbon

Readily oxidized C content was determined following modified Walkely and Black's method as described by Jackson (1958). One gram of sediment was placed in a 400 ml conical flask. Ten milliliter of 1 *N* potassium dichromate ($K_2Cr_2O_7$) solution was pipetted into the conical flask. Then 20 ml of concentrated sulfuric acid was added and the mixture was allowed to stand for 20-30 minutes. A blank was also run in the same manner. The contents were then diluted to 200 ml with distilled water. Further 10 ml of 85 per cent orthophosphoric acid, 0.2 g of sodium fluoride and 30 drops of diphenylamine indicator were added to each flask. The solution was back titrated with 0.5 *N* ferrous ammonium sulfate till a turbid blue colour changed to brilliant green. Soil organic carbon was calculated as given below:

$$\text{Total carbon (\%)} = \frac{(B - S) \times N \text{ of FAS} \times \text{meq. of C}}{\text{Weight of soil sample (g)} \times 0.76} \times 100$$

where,

B = volume of $K_2Cr_2O_7$ used used for titration of blank

S = volume of ferrous ammonium sulfate used for titration of sample

Milliequivalent weight of carbon = 0.003

$$N \text{ of ferrous ammonium sulfate (FAS)} = \frac{\text{Volume of } 1\,N\,K_2Cr_2O_7}{\text{Blank titre}}$$

100 = percentage conversion factor

0.76 = fraction of organic carbon which was oxidized to carbon dioxide

3.8.5 Calcium carbonate content ($CaCO_3$)

Carbonates in sediment samples were measured by acid neutralization method as described by Schollenberger (1945).

Five g sediment sample was transferred into a 300 ml tall beaker. Then 25 ml of 0.5 *N* HCl was added through a burette. The content was heated to boil gently for 5 minutes. After cooling, the contents were filtered and collected in a 250 ml Erlenmeyer flask .Then, the filtrate was titrated with 0.25 *N* NaOH after adding 2-3 drops of phenolphthalein indicator until the solution colour changed from colourless to persistent light pink colour.

$$CaCO_3 \text{ equivalent percent} = \frac{(\text{meq HCl added - meq NaOH used}) \times \text{meq wt. of } CaCO_3 \times 100}{\text{Oven dry mass of soil (g)}}$$

meq of acid or base = Titre × Normailty

3.8.6 Chemical fractions of metal in sediments

Three gram moist sediment portions were taken into 50 ml polycarbonate centrifuge tubes. An equivalent aliquot of sediment was oven dried at 105 ^0C for 48 h to determine the exact dry weight of sediment transferred. Wet sediment sample taken in centrifuge tube was sequentially extracted as per the scheme (Fig. 3.1) given by Ahnstrom and Parker (1999) to obtain the following five operationally defined fractions:

Fraction-1 (F_1) : Water soluble + exchangeable. Each sample was treated with 15 ml of 0.1 *M* $Sr(NO_3)_2$ and kept on a reciprocating shaker (150 rpm) for 2 h at room temperature. This fraction was collected by conducting two successive treatments for each sediment material.

Fraction-2 (F_2) : NaOAc (sodium acetate) extractable. The residue from F_1 was treated with 30 ml of 1 *M* NaOAc(adjusted to pH 5 with TMG glacial acetic acid) (Gibson and Farmer, 1986). The slurry was shaken as described above for 5 h. The cap of the centrifuge tubes was opened occasionally to expel CO_2.

Fraction-3 (F_3) : Oxidizable. The residue from F_2 was mixed with 5 ml of 5 per cent NaOCl (adjusted to pH 8.5 with TMG/HCl) and reacted in a water bath (90-95°C) for 30 minutes with the cap slightly ajar (Shuman, 1983). Every 10-15 minutes, the cap was tightened and the slurry was briefly vortex-mixed. This procedure was done three times successively for each sample.

Fraction-4 (F_4) : Reducible. Following the F_3 extraction, the residue was mixed with 20 ml of 0.2 *M* oxalic acid + 0.2 *M*

NH_4 oxalate + 0.1 *M* ascorbic acid (adjusted to pH 3 with TMG NH_4OH). The slurry was placed in a water bath (90-95°C) for 30 minutes (Shuman, 1982) with periodic mixing as for F_3. Each sample underwent 3 successive treatments.

All the slurries were centrifuged at 5000 rpm for 20 minutes and the supernatants were filtered (Whatman No. 42) and stored into plastic vials. Fraction 1 to 3 were acidified to 0.16 M HNO_3, A drop of toluene was added to the F_4 extracts to discourage bacterial growth. Schematic fractionation is indicated in Fig.

Fraction-5 (F_5) : Residual.

For analysis of residual trace metals in sediments, the solid was digested in a 5: 1 mixture of hydrofluoric acid and perchloric acids (Page *et al.,* 1982). Oven dried sediment was passed through a 0.15 mm sieve and 0.200 g of sediment sample was taken in a 30 ml platinum crucible. The sediment was wetted with a few drop of distilled water. One ml of $HClO_4$ and 5 ml of HF were added to the crucible. The crucible was heated till the sample dissolved completely. If there were traces of undissolved sample, 5 ml of HF was again added till the sample was dissolved completely. Thereafter, 5 ml of 6 *N* HCl + 5 ml water was added and crucible contents were heated just upto gentle boiling. Sample was filtered through Whatman No. 42 filter paper into a 50 ml volumetric flask and volume was made up to the mark. Using distilled water all the extracts from fractionation scheme including that of residual fraction were analyzed for Fe, Cu, Mn, Zn, Ni, Pb, Cd, Ca, Mg and Cr using atomic absorption spectrophotometer (Sparks 1996).

3.8.6.1 Total metal content

Total content of metals in sediments was calculated as sum all fractions.

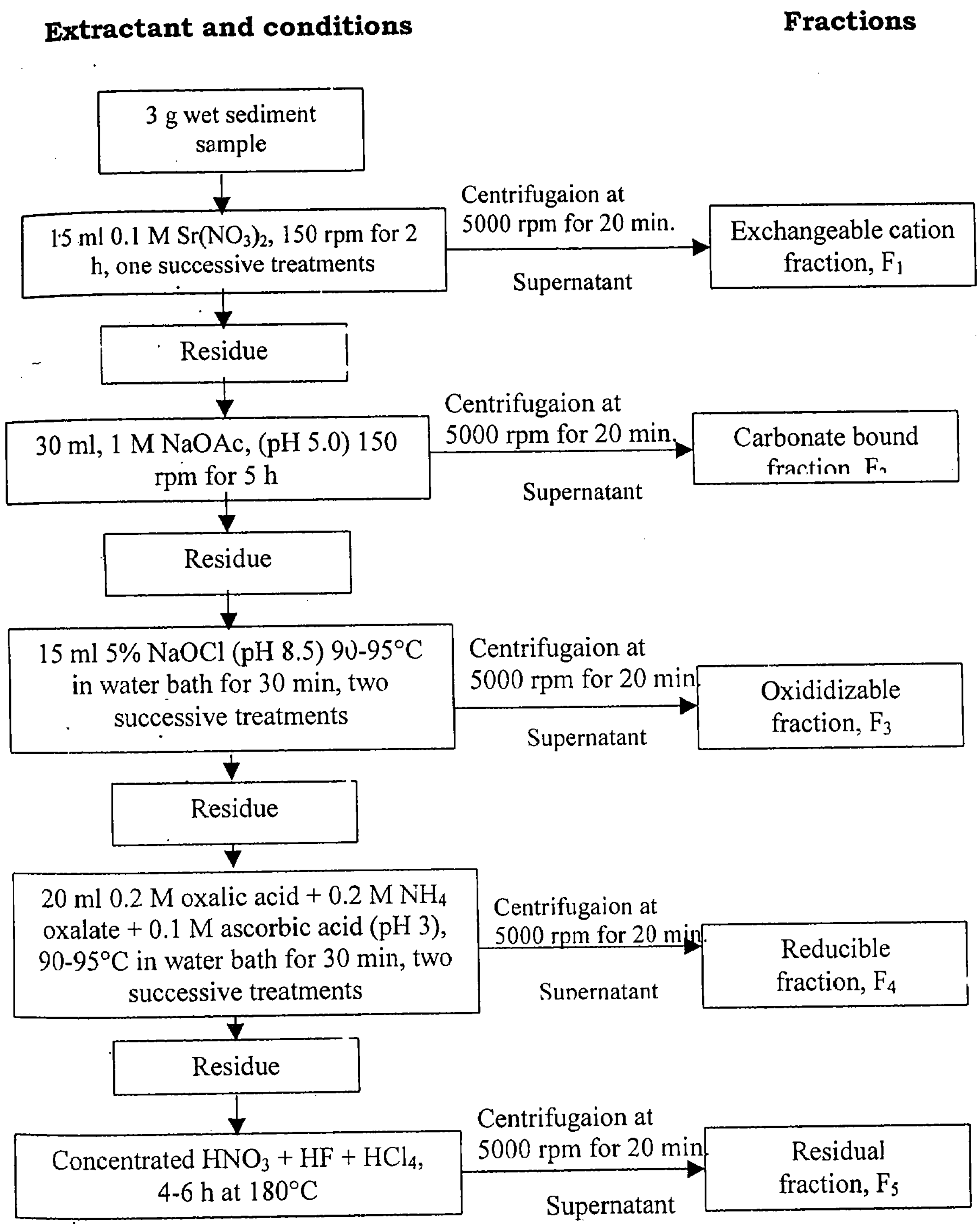

Fig 3.2: Fractionation scheme of heavy metals in sediments

3.9 Statistical Analysis

Statistical analysis of the data was performed as per the procedures outlined by Snedecor and Cochran (1967) with the help of a computer. The test of significance (F-test) was examined at probability levels of 1 and 5 per cent.

RESULTS
&
DISCUSSION

Results and Discussion

The results obtained in the present investigation are described in this chapter under the following heads:

4.1 Physico-chemical and microbiological properties of waters

4.2 Heavy metal concentration in waters

4.3 Physico-chemical properties of sediments

4.4 Different chemical pools of metals in sediments

4.5 Correlation studies

4.1 Physico-chemical and microbiological properties of waters

4.1.1 pH:

The data on seasonal variation in pH of waters of different lakes are presented in Table 4.1.

The values of pH of waters averaged over seasons from different lakes indicated that the highest pH was found in Nainital (8.45) followed by Bhimtal (8.25), Naukuchiatal (8.07), Ramtal and Hanumantal (8.06), Sitatal (8.05) and Punatal (7.96).

The pH values observed were in the same range as reported by earlier for Indian lakes (Paka and Rao, 1997; Tiwari, 1999; Patil *et al.*, 2004). Considering pH of range 6.5-8.5 as per the desirable pH range as the BIS criterion, these waters were safe even for potable use.

Table 4.1. Seasonal variation in pH of waters from different lakes

Season.	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	8.25	7.89	8.13	8.03	8.03	8.03	8.52	8.12
Autumn-03	8.14	7.92	7.69	7.87	7.90	7.88	8.21	7.94
Winter-03	8.22	8.05	8.01	8.05	8.08	8.06	8.46	8.13
Spring-04	8.28	8.15	8.01	8.08	8.06	8.10	8.48	8.16
Summer-04	8.36	8.22	8.05	8.18	8.19	8.18	8.60	8.25
Autumn-04	8.15	7.93	7.70	7.88	7.91	7.89	8.22	7.95
Winter-04	8.23	8.06	8.02	8.06	8.09	8.07	8.47	8.14
Spring-05	8.29	8.16	8.02	8.09	8.07	8.11	8.49	8.17
Summer-05	8.36	8.22	8.06	8.18	8.19	8.19	8.63	8.26
Mean	8.25	8.07	7.96	8.05	8.06	8.06	8.45	
Effect	**Season**	**Lake**	**Season x Lake**					
C.D. (p =0.05)	0.02	0.01	0.04					

The values of pH averaged over lakes revealed that the highest pH of waters was found during summers while the lowest was noted during autumns in both years. The pH values during autumn, winter, spring and summer of 2003-04 were statistically *at par* with the values found during autumn, winter, spring and summer of 2004-05, respectively. A significant increase was noted in pH after autumns up to summers in both years.

The interaction effect between seasons and lakes was also significant. The highest pH was found in Nainital during summer-2005 (8.63) while the lowest was noted in Naukuchiatal during autumn-2003 (7.69).

4.1.2 Electrical conductivity (E.C.)

The data on seasonal variation in electrical conductivity of waters of different lakes are presented in Table 4.2.

The values of electrical conductivity of waters from different lakes averaged over seasons indicated that the highest electrical conductivity was found in Nainital (0.56 mS m^{-1}) followed by Bhimtal (0.19 mS m^{-1}), Naukuchiatal (0.19 mS m^{-1}), Ramtal and Hanumantal (0.16 mS m^{-1}), Sitatal (0.15 mS m^{-1}) and Punatal (0.13 mS m^{-1}).

These results were in agreement with the observations recorded for several Indian lakes (Sarwar *et al.*, 1996; Tiwari, 1999; Patil and Tijare, 2001). The values of electrical conductivity fell within the tolerance limit (1.5 mS m^{-1}) for drinking purpose. The observed values of electrical conductivity of waters of these lakes also indicated that waters of lakes could be safely used for irrigation purpose.

Table 4.2. Seasonal variation in electrical conductivity (mS cm^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	0.20	0.20	0.14	0.14	0.15	0.14	0.62	0.23
Autumn-03	0.15	0.15	0.08	0.13	0.13	0.13	0.41	0.17
Winter-03	0.18	0.17	0.14	0.15	0.15	0.15	0.59	0.22
Spring-04	0.21	0.20	0.13	0.15	0.16	0.16	0.60	0.23
Summer-04	0.23	0.22	0.16	0.19	0.20	0.19	0.63	0.26
Autumn-04	0.14	0.15	0.07	0.12	0.12	0.12	0.37	0.16
Winter-04	0.19	0.17	0.14	0.15	0.16	0.16	0.57	0.22
Spring-05	0.20	0.21	0.15	0.16	0.16	0.16	0.61	0.23
Summer-05	0.23	0.23	0.16	0.19	0.20	0.20	0.63	0.26
Mean	0.19	0.19	0.13	0.15	0.16	0.16	0.56	

Effcct	**Season**	**Lake**	**Season x Lake**
C.D. (p =0.05)	0.01	0.01	0.03

The values of electrical conductivity averaged over lakes revealed that the highest electrical conductivity of waters was found during summers while the lowest was noted during autumns in both years. The electrical conductivity values during winter, spring and summer of 2003-04 were statistically *at par* with the values found during winter, spring and summer of 2004-05, respectively. A significant increase in electrical conductivity was noted after autumns up to summers during both years.

The interaction effect between seasons and lakes was significant. The highest electrical conductivity was found in Nainital during summers of 2004 and 2005 (0.63 mS m^{-1}) while the lowest was noted in Punatal during autumn-2004 (0.07 mS m^{-1}).

4.1.3 Dissolved oxygen (DO)

The data on seasonal variation in dissolved oxygen of waters of different lakes are presented in Table 4.3.

The values of dissolved oxygen in waters from different lakes averaged over seasons indicated that the highest dissolved oxygen was found in Punatal (8.64 mg L^{-1}) followed by Naukuchiatal (7.73 mg L^{-1}), Sitatal (7.66 mg L^{-1}), Hanumantal (7.63 mg L^{-1}), Ramtal (7.62 mg L^{-1}), Bhimtal (7.19 mg L^{-1}) and Nainital (4.18 mg L^{-1}). The averaged values of DO in Naukuchiatal, Sitatal, Ramtal and Hanumantal were statistically *at par.*

These results are in agreement with those recorded for other lakes by Paka and Rao (1997); Bhatt *et al.* (1999) and Sivakumar (2000). The values of dissolved oxygen in these lakes were above the

Table 4.3. Seasonal variation in dissolved oxygen (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	6.18	7.33	7.63	7.37	7.36	7.34	3.12	6.62
Autumn-03	8.03	8.21	9.66	8.11	8.08	8.09	5.15	7.91
Winter-03	7.78	8.13	9.30	7.93	7.85	7.89	4.98	7.69
Spring-04	7.46	7.97	8.62	7.54	7.48	7.47	3.97	7.22
Summer-04	6.67	7.57	8.11	7.48	7.44	7.47	3.20	6.85
Autumn-04	7.69	7.77	9.48	8.13	8.09	8.07	5.02	7.75
Winter-04	7.42	7.73	9.20	7.78	7.77	7.78	4.78	7.49
Spring-05	7.27	7.54	8.17	7.38	7.33	7.34	4.15	7.03
Summer-05	6.22	7.28	7.58	7.21	7.19	7.18	3.23	6.56
Mean	7.19	7.73	8.64	7.66	7.62	7.63	4.18	

Effect	**Season**	**Lake**	**Season x Lake**
C.D. (p =0.05)	0.34	0.30	ns

tolerance limit (5 mg L^{-1}) as prescribed by the BIS except in case of Nainital where the values often fell below the prescribed limit.

The values of dissolved oxygen averaged over lakes revealed that the highest dissolved oxygen of waters was found during autumns while the lowest was noted during summers in both years. The values of dissolved oxygen during autumn, winter, spring and summer of 2003-04 were statistically *at par* with the values found during autumn, winter, spring and summer of 2004-05, respectively. A continuous reduction in dissolved oxygen was noted after autumns up to summers during both years.

The interaction effect between seasons and lakes was not significant.

4.1.4 Biological oxygen demand (BOD)

The data on seasonal variation in biological oxygen demand of waters of different lakes are presented in Table 4.4.

The values of biological oxygen demand of waters from different lakes averaged over seasons indicated that the highest biological oxygen demand was found in Nainital (2.54 mg L^{-1}) followed by Bhimtal (1.98 mg L^{-1}), Naukuchiatal (1.58 mg L^{-1}), Ramtal (1.10 mg L^{-1}), Hanumantal (1.09 mg L^{-1}), Sitatal (1.02 mg L^{-1}) and Punatal (0.74 mg L^{-1}). The averaged values of BOD in Ramtal and Hanumantal were statistically *at par*.

These values were in the same range as reported earlier (Rasool *et al.*, 2003; Kudari *et al.*, 2004) for Indian lakes. Considering 3 mg L^{-1}

Table 4.4. Seasonal variation in biological oxygen demand (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	2.40	1.79	1.10	1.28	1.36	1.34	2.81	1.73
Autumn-03	1.38	1.00	0.47	0.77	0.78	0.77	2.11	1.04
Winter-03	1.78	1.11	0.52	0.88	0.92	0.90	2.40	1.22
Spring-04	2.11	2.00	0.70	0.96	0.97	0.97	2.50	1.46
Summer-04	2.60	2.11	1.11	1.38	1.47	1.45	2.96	1.87
Autumn-04	1.44	0.94	0.43	0.82	0.83	0.83	2.19	1.07
Winter-04	1.73	1.09	0.55	0.61	0.96	0.97	2.46	1.19
Spring-05	2.00	1.95	0.73	1.08	1.09	1.11	2.64	1.51
Summer-05	2.38	2.22	1.08	1.39	1.51	1.50	2.81	1.84
Mean	1.98	1.58	0.74	1.02	1.10	1.09	2.54	
Effect	**Season**	**Lake**	**Season x Lake**					
C.D. (p =0.05)	0.07	0.06	0.19					

as the maximum value of BOD as per the BIS criterion, these waters were in good condition.

The values averaged over lakes revealed that the highest biological oxygen demand of waters was found during summers while the lowest was noted during autumns in both years. The values of biological oxygen demand during autumn, winter, spring and summer of 2003-04 were statistically *at par* with the values found during winter, spring and summer of 2004-05, respectively. A significant increase was noted in biological oxygen demand after autumns up to summers during both years.

The interaction effect between seasons and lakes was significant. The highest biological oxygen demand was found in Nainital during summers of 2004 (2.96 mg L^{-1}) while the lowest was noted in Punatal during autumn-2004 (0.43 mg L^{-1}).

4.1.5 Chemical oxygen demand (COD)

The data on seasonal variation in chemical oxygen demand of waters (COD) of different lakes are presented in Table 4.5.

The values of chemical oxygen demand of waters from different lakes averaged over seasons indicated that the highest chemical oxygen demand was found in Nainital (294.9 mg L^{-1}) followed by Bhimtal (152.6 mg L^{-1}), Naukuchiatal (133.6 mg L^{-1}), Ramtal (123.9 mg L^{-1}), Hanumantal (123.7 mg L^{-1}), Sitatal (121.7 mg L^{-1}) and Punatal (86.9 mg L^{-1}). The averaged values of chemical oxygen demand in Sitatal, Ramtal and Hanumantal were statistically *at par*.

Table 4.5. Seasonal variation in chemical oxygen demand (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	203.3	172.8	105.7	167.8	171.8	168.8	355.8	192.3
Autumn-03	109.8	91.5	66.1	97.6	99.6	98.6	254.2	116.8
Winter-03	122.0	107.8	75.2	106.8	109.8	109.8	274.5	129.4
Spring-04	166.7	132.2	95.6	113.9	116.9	117.9	299.9	149.0
Summer-04	188.1	182.0	103.7	138.3	137.3	140.3	373.1	180.4
Autumn-04	126.1	106.8	65.1	91.5	93.5	95.6	223.7	114.6
Winter-04	132.2	110.8	71.2	110.8	111.8	111.8	244.0	127.5
Spring-05	141.3	126.1	91.5	126.1	130.1	127.1	284.7	146.7
Summer-05	184.0	172.8	107.8	142.3	144.4	143.4	344.7	177.0
Mean	152.6	133.6	86.9	121.7	123.9	123.7	294.9	
Effect	**Season**	**Lake**	**Season x Lake**					
C.D. (p =0.05)	7.5	6.6	19.8					

Similar range of chemically oxygen demand value for the waters of various lakes was also reported by several workers (Rasool *et al.*, 2003; Kudari *et al.*, 2004; Patil *et al.*, 2004).

The values averaged over lakes revealed that the highest chemical oxygen demand of waters was found during summers while the lowest was noted during autumns in both years. The chemical oxygen demand values during autumn, winter, spring and summer of 2003-04 were statistically *at par* with the values found during autumn, winter, spring and summer of 2004-05, respectively. However, slightly lower chemical oxygen demand was noted in all seasons during 2004-05 as compared to all seasons of 2003-04, respectively. A significant increase was noted in chemical oxygen demand after autumns up to summers during both years.

The interaction between seasons and lakes was also significant. The highest chemical oxygen demand was found in Nainital during summers of 2004 (373.1 mg L^{-1}) while the lowest was noted in Punatal during autumn-2004 (65.1 mg L^{-1}).

4.1.6 Ammonical-nitrogen (NH_4^+-N)

The data on seasonal variation in ammonical-nitrogen of waters of different lakes are presented in Table 4.6.

The values of NH_4^+-N of waters from different lakes averaged over seasons indicated that the highest NH_4^+-N was found in Nainital (1.63 mg L^{-1}) followed by Bhimtal (1.04 mg L^{-1}), Naukuchiatal (0.76 mg L^{-1}), Hanumantal (0.50 mg L^{-1}), Ramtal and Sitatal (0.44 mg L^{-1}) and Punatal (0.32 mg L^{-1}).

Table 4.6. Seasonal variation in ammonical-nitrogen (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	1.18	0.95	0.23	0.46	0.49	0.46	1.93	0.81
Autumn-03	0.57	0.51	0.14	0.24	0.26	0.26	1.26	0.46
Winter-03	0.98	0.31	0.20	0.35	0.35	0.36	1.36	0.56
Spring-04	1.07	0.47	0.29	0.41	0.42	0.42	1.44	0.64
Summer-04	1.21	1.66	0.90	1.03	1.01	1.53	2.07	1.34
Autumn-04	0.88	0.45	0.16	0.24	0.24	0.25	1.32	0.51
Winter-04	1.07	0.65	0.24	0.33	0.34	0.34	1.48	0.63
Spring-05	1.14	0.87	0.32	0.40	0.40	0.41	1.75	0.75
Summer-05	1.26	0.98	0.37	0.47	0.48	0.48	2.01	0.86
Mean	1.04	0.76	0.32	0.44	0.44	0.50	1.63	
Effect	**Season**	**Lake**	**Season x Lake**					
C.D. (p =0.05)	0.04	0.03	0.10					

The values of NH_4^+-N concentration in these lakes were below well tolerance limit (1.55 mg L^{-1}) as prescribed by BIS except in the case of Nainital. Ammonical-nitrogen in waters of these lakes fell in the range of 0.051 to 28.1 mg L^{-1} which had been reported by various workers for different lakes (Sarwar *et al.*, 1996; Bhatt *et al.*, 1999; Khalil, 2000; Kudari *et al.*, 2004).

The values averaged over lakes revealed that the highest NH_4^+-N of waters was found during summers while the lowest was noted during autumns in both years. The values of NH_4^+-N during autumn and winter of 2003-04 were statistically *at par* with the values found during autumn and winter of 2004-05, respectively. A significant increase in NH_4^+-N was noted in springs and summers during 2004-05 as compared to the values observed in the respective seasons of 2003-04. A significant increase was noted in NH_4^+-N after autumns up to summers during both years except in winter-2004.

The interaction between seasons and lakes was significant. The highest NH_4^+-N was found in Nainital during summers of 2004 (2.07 mg L^{-1}) while the lowest was noted in Punatal during autumn-2003 (0.14 mg L^{-1}).

4.1.7 Nitrate-nitrogen (NO_3^--N)

The data on seasonal variation in nitrate-nitrogen of waters of different lakes are presented in Table 4.7.

The values of NO_3^--N of waters from different lakes averaged over seasons indicated that the highest NO_3^--N was found in Nainital (5.66 mg L^{-1}) followed by Bhimtal (2.64 mg L^{-1}), Naukuchiatal (1.86 mg L^{-1}),

Table 4.7. Seasonal variation in nitrate-nitrogen (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	3.13	1.41	1.41	1.57	1.57	1.58	3.74	2.06
Autumn-03	1.57	0.78	0.40	0.78	0.79	0.78	2.98	1.15
Winter-03	2.99	2.20	0.94	2.35	2.35	2.35	7.47	2.95
Spring-04	3.13	2.38	0.92	2.38	2.35	2.39	7.81	3.05
Summer-04	3.29	2.40	1.28	2.51	2.46	2.50	7.98	3.20
Autumn-04	1.38	1.00	0.48	1.10	1.14	1.11	3.52	1.39
Winter-04	1.79	1.71	0.78	1.36	1.37	1.38	4.76	1.88
Spring-05	2.99	2.50	0.96	2.62	2.64	2.65	5.55	2.85
Summer-05	3.52	2.36	1.20	2.79	2.79	2.81	7.10	3.22
Mean	2.64	1.86	0.93	1.94	1.94	1.95	5.66	
Effect	Season	Lake	Season x Lake					
C.D. (p =0.05)	0.14	0.12	0.36					

Hanumantal (1.95 mg L^{-1}), Ramtal and Sitatal (1.94 mg L^{-1}) and Punatal (0.93 mg L^{-1}). The averaged values of NO_3^--N in Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par.*

These values were in the same range as reported earlier for Indian lakes (Khan and Chowdhary, 1994; Sarwar *et al.*, 1996; Paka and Rao, 1997; Patil *et al.*, 2004). Considering 45 mg L^{-1} as the desirable range of NO_3^--N as per the BIS criterion, these waters were safe even for potable use.

The values averaged over lakes revealed that the highest NO_3^--N of waters was found during summers while the lowest was noted during autumns in both years. The values of NO_3^--N during winter and summer of 2003-04 were statistically *at par* with the values found during respective seasons of 2004-05. A significant increase in NO_3^--N was noted in autumn of 2004-05 as compared to autumn of 2003-04. A significant reduction was noted in NO_3^--N in spring of 2004-05 as compared to spring of 2003-04.

The interaction between seasons and lakes was significant. The highest NO_3^--N was found in Nainital during summers of 2004 (7.98 mg L^{-1}) while the lowest value was noted in Punatal during autumn-2003 (0.40 mg L^{-1}).

4.1.8 Phosphate-phosphorus (PO_4^{2-}-P)

The data on seasonal variation in phosphate-phosphorus of waters of different lakes are presented in Table 4.8.

The values of PO_4^{2-}-P of waters from different lakes averaged over seasons indicated that the highest PO_4^{2-}-P was found in Nainital (0.92

Table 4.8. Seasonal variation in phosphate-phosphorus (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	0.26	0.18	0.08	0.18	0.19	0.19	0.86	0.28
Autumn-03	0.19	0.09	0.05	0.09	0.11	0.10	0.70	0.19
Winter-03	0.25	0.11	0.06	0.13	0.16	0.14	0.80	0.24
Spring-04	0.26	0.13	0.08	0.14	0.16	0.15	0.97	0.27
Summer-04	0.31	0.19	0.12	0.21	0.22	0.21	1.08	0.34
Autumn-04	0.22	0.10	0.06	0.12	0.13	0.11	0.77	0.22
Winter-04	0.33	0.13	0.09	0.13	0.17	0.15	0.97	0.28
Spring-05	0.34	0.12	0.10	0.19	0.18	0.19	1.00	0.30
Summer-05	0.37	0.18	0.14	0.23	0.25	0.24	1.14	0.37
Mean	0.28	0.14	0.09	0.16	0.18	0.17	0.92	
Effect	Season	Lake	Season x Lake					
C.D. (p =0.05)	0.02	0.02	0.05					

mg L^{-1}) followed by Bhimtal (0.28 mg L^{-1}), Ramtal (0.18 mg L^{-1}), Hanumantal (0.17 mg L^{-1}), Sitatal (0.16 mg L^{-1}), Naukuchiatal (0.14 mg L^{-1}) and Punatal (0.09 mg L^{-1}). The averaged values of PO_4^{2-}-P in Sitatal and Hanumantal and Ramtal and Hanumantal were statistically *at par.*

The results were in agreement with the observations recorded earlier for several Indian lakes (Khan and Chowdhary, 1994; Sarwar *et al.*, 1996; Paka and Rao, 1997). The values of PO_4^{2-}-P concentration fell within the tolerance limit (2 mg L-1) as prescribed by WHO for drinking purpose.

The values averaged over lakes revealed that the highest PO_4^{2-}-P of waters was found during summers while the lowest was noted during autumns in both years. A significant increase in PO_4^{2-}-P was noted in all seasons of 2004-05 as compared to respective seasons of 2003-04. A significant and continuous increase was noted in PO_4^{2-}-P after autumns up to summers during both years.

The interaction between seasons and lakes was significant. The highest PO_4^{2-}-P was found in Nainital during summers of 2004 (1.08 mg L^{-1}) while the lowest was noted in Punatal during autumn-2003 (0.05 mg L^{-1}).

4.1.9 Sulphate-sulphur (SO_4^{2-}-S)

The data on seasonal variation in sulphate-sulphur of waters of different lakes are presented in Table 4.9.

The values of SO_4^{2-}-S of waters from different lakes averaged over seasons indicated that the highest SO_4^{2-}-S was found in Nainital (40.31 mg L^{-1}) followed by Bhimtal (7.60 mg L^{-1}), Ramtal (5.66 mg L^{-1}),

Table 4.9. Seasonal variation in sulphate-sulphur (mg L^{-1}) of waters of different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	8.64	4.28	2.94	5.89	6.12	6.15	44.14	11.17
Autumn-03	6.95	2.30	1.57	4.82	4.97	4.89	33.44	8.42
Winter-03	7.49	2.94	2.41	5.62	5.69	5.67	37.19	9.57
Spring-04	7.76	3.48	2.67	5.69	5.73	5.73	42.27	10.48
Summer-04	9.11	4.86	3.06	5.96	6.00	5.98	47.50	11.78
Autumn-04	5.72	2.40	1.50	4.91	4.92	4.92	30.74	7.87
Winter-04	6.28	3.02	1.99	5.35	5.40	5.37	38.08	9.36
Spring-05	7.31	3.52	2.80	5.84	5.89	5.88	41.06	10.33
Summer-05	9.17	4.79	2.99	6.18	6.25	6.21	48.35	11.99
Mean	7.60	3.51	2.44	5.58	5.66	5.64	40.31	
Effect	**Season**	**Lake**	**Season x Lake**					
C.D. (p =0.05)	0.74	0.65	1.96					

Hanumantal (5.64 mg L^{-1}), Sitatal (5.58 mg L^{-1}), Naukuchiatal (3.51 mg L^{-1}) and Punatal (2.44 mg L^{-1}). The averaged values of SO_4^{2-}-S in Sitatal, Ramtal and Hanumantal were statistically *at par.*

These results are in agreement with those recorded by Khalil (2000); Rasool *et al.* (1999) and Kudari *et al.* (2004) for various lakes. The concentration values of sulphate-sulphur in these lakes were well below than tolerance limit (200 mg L^{-1}) as prescribed by BIS.

The values averaged over lakes revealed that the highest SO_4^{2-}-S of waters was found during summers while the lowest was noted during autumns in both years. The values of SO_4^{2-}-S during autumn, winter, spring and summer of 2003-04 were statistically *at par* with the values found during respective seasons of 2004-05. However, an increase in SO_4^{2-}-S was noted in all seasons during autumn of 2004 to summers of 2005.

The interaction between seasons and lakes was significant. The highest SO_4^{2-}-S was found in Nainital during summers of 2005 (48.35 mg L^{-1}) while the lowest was noted in Punatal during autumn-2004 (1.50 mg L^{-1}).

4.1.10 Chloride (Cl^-)

The data on seasonal variation in chloride content of waters of different lakes are presented in Table 4.10.

The values of Cl^- of waters from different lakes averaged over seasons indicated that the highest Cl^- was found in Nainital (20.66 mg L^{-1}) followed by Bhimtal (12.05 mg L^{-1}), Naukuchiatal (12.91 mg L^{-1}), Ramtal (11.03 mg L^{-1}), Hanumantal (10.98 mg L^{-1}), Sitatal (10.89 mg

Table 4.10. Seasonal variation in chloride (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	8.66	11.55	7.22	10.11	10.11	11.55	23.10	11.76
Autumn-03	11.55	11.55	6.50	5.05	6.06	5.77	12.27	8.39
Winter-03	11.55	12.27	8.66	15.16	13.71	14.44	15.88	13.10
Spring-04	8.66	10.00	7.22	10.11	10.11	9.38	20.21	10.81
Summer-04	15.16	13.71	10.11	12.27	12.99	12.27	25.26	14.54
Autumn-04	9.72	10.03	5.73	6.31	6.34	6.38	15.90	8.63
Winter-04	12.57	13.87	6.68	7.72	8.11	7.87	19.70	10.93
Spring-05	14.92	16.55	10.85	14.60	15.60	15.58	23.77	15.98
Summer-05	15.63	16.64	11.53	16.64	16.25	15.60	29.85	17.45
Mean	12.05	12.91	8.28	10.89	11.03	10.98	20.66	

Effect	**Season**	**Lake**	**Season x Lake**
C.D. (p =0.05)	0.61	0.54	1.62

L^{-1}) and Punatal (8.28 mg L^{-1}). The averaged values of Cl^- in Sitatal, Ramtal and Hanumantal were statistically *at par.*

These values were in the same range as reported earlier for Indian lakes by several lakes (Khan and Chowdhary, 1994; Patil and Tijare, 2001; Kudari *et al.*, 2004). Considering 250 mg Cl L^{-1} as the maximum tolerance value of Cl^- as per the BIS criterion, these waters were safe even for potable use.

The values averaged over lakes revealed that the highest Cl^- of waters was found during summers while the lowest was noted during autumns in both years. A significant increase was noted in spring and summer of 2004-05 as compared to respective seasons of 2003-04.

As regards the interaction of seasons and lakes, the highest Cl^- was found in Nainital during summers of 2005 (29.85 mg L^{-1}) while the lowest was noted in Sitatal during autumn-2003 (5.05 mg L^{-1}).

4.1.11 Potassium (K^+)

The data on seasonal variation in potassium content of waters of different lakes are presented in Table 4.11.

The values of K^+ of waters from different lakes averaged over seasons indicated that the highest K^+ was found in Nainital (7.15 mg L^{-1}) followed by Bhimtal (3.99 mg L^{-1}), Naukuchiatal (3.55 mg L^{-1}), Punatal (2.64 mg L^{-1}), Sitatal (2.57 mg L^{-1}), Hanumantal (2.56 mg L^{-1}) and Ramtal (2.45 mg L^{-1}). The averaged values of K^+ in Sitatal and Hanumantal were statistically *at par.*

A similar range was also reported earlier by several other workers (Sarwar *et al.*, 1996; Tiwari, 1999; Patil *et al.*, 2004).

Table 4.11. Seasonal variation in potassium (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	5.37	4.47	2.72	3.49	3.08	3.07	9.25	4.49
Autumn-03	3.06	2.35	2.11	2.03	2.01	2.08	5.41	2.72
Winter-03	3.42	3.39	2.49	2.65	2.42	2.34	5.92	3.23
Spring-04	4.03	3.61	2.85	2.27	2.30	2.55	7.42	3.57
Summer-04	4.72	4.36	3.08	2.83	2.73	3.01	8.78	4.21
Autumn-04	3.07	2.36	2.12	2.04	2.02	2.08	5.43	2.73
Winter-04	3.43	3.40	2.49	2.66	2.43	2.35	5.94	3.24
Spring-05	4.04	3.62	2.86	2.28	2.31	2.56	7.44	3.59
Summer-05	4.73	4.38	3.09	2.84	2.74	3.02	8.81	4.23
Mean	3.99	3.55	2.64	2.57	2.45	2.56	7.15	
Effect	Season	Lake	Season x Lake					
C.D. (p =0.05)	0.10	0.09	0.27					

The values averaged over lakes revealed that the highest K^+ of waters was found during summers while the lowest was noted during autumns in both years. The contents of K^+ during autumn, winter, spring and summer of 2003-04 were statistically *at par* with the values found during respective seasons of 2004-05. However, an increase in K^+ was noted in all seasons during 2004-05.

As regards the interaction of seasons and lakes, the highest K^+ was found in Nainital during summers of 2005 (8.81 mg L^{-1}) while the lowest was noted in Ramtal during autumn-2003 (2.01 mg L^{-1}).

4.1.12 Sodium (Na^+)

The data on seasonal variation in sodium content of waters of different lakes are presented in Table 4.12.

The values of Na^+ of waters from different lakes averaged over seasons indicated that the highest Na^+ was found in Nainital (35.77 mg L^{-1}) followed by Bhimtal (19.93 mg L^{-1}), Naukuchiatal (17.74 mg L^{-1}), Punatal (13.22 mg L^{-1}), Sitatal (12.83 mg L^{-1}), Hanumantal (12.81 mg L^{-1}) and Ramtal (12.23 mg L^{-1}). The averaged values of Na^+ in Punatal, Sitatal and Hanumantal were statistically *at par*.

Sodium in waters of these lakes except Nainital fell in the range of 4.0 to 23.25 mg L^{-1} reported earlier by various workers for different lakes (Sarwar *et al.*, 1996; Tiwari, 1999; Patil *et al.*, 2004). Considering 200 mg L^{-1} as the desirable value of Na as per the BIS criterion, these waters were safe even for potable use.

The values averaged over lakes revealed that the highest Na^+ content in waters was found during summers while the lowest was

Table 4.12. Seasonal variation in sodium (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	26.85	22.33	13.60	17.46	15.40	15.36	46.25	22.46
Autumn-03	15.31	11.76	10.54	10.16	10.04	10.30	27.06	13.61
Winter-03	17.10	16.94	12.43	13.26	12.09	11.70	29.59	16.16
Spring-04	20.15	18.05	14.25	11.35	11.49	12.74	37.09	17.87
Summer-04	23.58	21.81	15.39	14.13	13.65	15.06	43.89	21.07
Autumn-04	15.36	11.80	10.58	10.20	10.08	12.42	27.15	13.65
Winter-04	17.15	17.00	12.47	13.31	12.13	11.74	29.69	16.21
Spring-05	20.22	18.11	14.30	11.39	11.53	12.78	37.22	17.93
Summer-05	23.66	21.89	15.44	14.18	13.70	15.11	44.03	21.12
Mean	19.93	17.74	13.22	12.83	12.23	12.81	35.77	

Effect	**Season**	**Lake**	**Season x Lake**
C.D. (p =0.05)	0.52	0.46	1.37

noted during autumns in both years. The content of Na^+ during autumn, winter, spring and summer of 2003-04 were statistically *at par* with the values found during respective seasons of 2004-05.

As regards the interaction, the highest Na^+ was found in Nainital during summers of 2005 (44.03 mg L^{-1}) while the lowest was noted in Ramtal during autumn-2003 (10.04 mg L^{-1}).

4.1.13 Calcium (Ca^{2+})

The data on seasonal variation in calcium content of waters of different lakes are presented in Table 4.13.

The values of Ca^{2+} of waters from different lakes averaged over seasons indicated that the highest Ca^{2+} was found in Nainital (39.51 mg L^{-1}) followed by Bhimtal (22.44 mg L^{-1}), Naukuchiatal (17.72 mg L^{-1}), Sitatal (16.83 mg L^{-1}), Ramtal (16.42 mg L^{-1}), Hanumantal (14.79 mg L^{-1}) and Punatal (11.38 mg L^{-1}). The averaged values of Ca^{2+}in Sitatal and Ramtal were statistically *at par*.

These values were in the same range as reported by earlier workers for Indian lakes (Khan and Chowdhary, 1994; Paka and Rao, 1997; Tiwari, 1999; Patil *et al.*, 2004). Considering 75 mg L^{-1} as the desirable value of calcium as prescribed the BIS, these waters were safe for even potable use.

The values averaged over lakes revealed that the highest Ca^{2+} of waters was found during summers while the lowest was noted during autumns in both years. The values of Ca^{2+} during autumn of 2003-04 were statistically *at par* with the values found during autumn of 2004-05. A significant reduction in Ca^{2+} concentration was noted during

Table 4.13. Seasonal variation in calcium (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	25.90	25.07	12.36	21.90	20.97	18.42	37.63	23.18
Autumn-03	13.91	10.86	8.64	12.38	11.81	10.87	23.11	13.08
Winter-03	20.74	18.94	9.80	15.65	14.38	11.93	46.28	19.67
Spring-04	22.65	16.47	12.70	19.01	16.76	15.58	52.52	22.24
Summer-04	25.15	15.35	12.95	23.12	23.93	19.32	38.88	22.67
Autumn-04	11.56	12.30	6.56	12.70	10.42	9.80	28.61	13.14
Winter-04	22.49	20.19	8.03	9.69	9.42	10.89	39.82	17.22
Spring-05	19.84	14.52	11.27	11.92	13.88	11.92	41.95	17.90
Summer-05	39.68	25.74	20.10	25.08	26.19	24.41	46.82	29.72
Mean	22.44	17.72	11.38	16.83	16.42	14.79	39.51	

Effect	Season	Lake	Season x Lake
C.D. (p =0.05)	0.84	0.74	2.21

winter and spring of 2004-05 as compared to the values observed during respective seasons of 2003-04.

As regards the interaction effect of seasons with lakes, the highest Ca^{2+} was found in Nainital during summers of 2004 (52.52 mg L^{-1}) while the lowest was noted in Punatal during autumn-2004 (6.56 mg L^{-1}).

4.1.14 Magnesium (Mg^{2+})

The data on seasonal variation in magnesium content of waters of different lakes are presented in Table 4.14.

The values of Mg^{2+} of waters from different lakes averaged over seasons indicated that the highest Mg^{2+} was found in Nainital (9.70 mg L^{-1}) followed by Bhimtal (6.72 mg L^{-1}), Naukuchiatal (6.65 mg L^{-1}), Hanumantal (6.34 mg L^{-1}), Ramtal (6.30 mg L^{-1}), Sitatal (6.06 mg L^{-1}) and Punatal (5.50 mg L^{-1}). The averaged values of Mg^{2+} in Bhimtal, Naukuchiatal, Ramtal and Hanumantal were statistically *at par*.

The results were also in agreement with the observations recorded for several others Indian lakes (Dhamija and Jain, 1995; Tiwari, 1999; Patil and Tijare 2001; Patil *et al.*, 2004). The values of magnesium concentration fell within the tolerance limit (30 mg L^{-1}) for drinking purpose.

The values averaged over lakes revealed that the highest Mg^{2+} in waters was found during summers while the lowest was noted during autumns in both years. A significant increase was noted in Mg^{2+} concentration during autumn of 2004-05 as compared to the value

Table 4.14. Seasonal variation in magnesium (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	8.32	7.15	7.55	8.11	8.58	8.57	11.07	8.48
Autumn-03	4.50	6.65	4.33	4.88	4.90	4.94	7.82	5.43
Winter-03	5.56	7.02	5.32	5.64	5.27	5.39	9.39	6.23
Spring-04	8.05	6.62	5.77	6.40	6.33	6.33	10.00	7.07
Summer-04	8.55	6.50	4.95	6.91	7.65	8.03	10.48	7.58
Autumn-04	6.16	6.10	6.23	6.27	6.36	6.30	6.55	6.28
Winter-04	5.42	4.71	4.46	4.35	4.52	4.46	10.22	5.45
Spring-05	6.32	6.64	5.51	5.51	5.53	5.48	10.69	6.52
Summer-05	6.60	8.43	5.38	6.48	7.56	7.60	11.08	7.73
Mean	6.72	6.65	5.50	6.06	6.30	6.34	9.70	
Effects	**Season**	**Lake**	**Season x Lake**					
C.D. ($p = 0.05$)	0.25	0.22	0.66					

observed during respective season of 2003-04. During winter-2004 as compared to winter 2003 a significant reduction in Mg^{2+} was noted.

As regards the interaction effect of seasons and lakes, the highest Mg^{2+} was found in Nainital during summer of 2005 (11.08 mg L^{-1}) while the lowest was noted in Punatal during autumn-2003 (4.33 mg L^{-1}).

4.1.15 Total hardness (as $CaCO_3$)

The data on seasonal variation in total hardness of waters of different lakes are presented in Table 4.15.

The values of total hardness of waters from different lakes averaged over seasons indicated that the highest total hardness was found in Nainital (139.1 mg L^{-1}) followed by Bhimtal (84.0 mg L^{-1}), Naukuchiatal (72.0 mg L^{-1}), Ramtal (67.4 mg L^{-1}), Sitatal (67.3 mg L^{-1}), Hanumantal (63.4 mg L^{-1}) and Punatal (51.4 mg L^{-1}). The averaged values of total hardness in Sitatal and Ramtal were statistically *at par.*

The values of total hardness in these lakes were below the tolerance limit (300 mg L^{-1}) prescribed by BIS. These results were in good agreement with those obtained by Dhamija and Jain (1995); Paka and Rao (1997); Sivakumar (2000) and Radhika *et al.* (1999) for various lakes.

The values averaged over lakes revealed that the highest total hardness of waters was found during summers while the lowest was noted during autumns in both years. A significant increase was noted during autumn and summer of 2004-05 as compared to the values observed during respective seasons of 2003-04. During winter and spring of 2004-05 a significant reduction in total hardness was noted

Table 4.15. Seasonal variation in total hardness (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	99.4	92.4	62.3	88.5	88.1	81.8	140.1	93.2
Autumn-03	53.5	54.9	39.6	51.3	49.9	47.8	90.3	55.3
Winter-03	75.0	76.6	46.7	62.6	57.9	52.3	154.7	75.1
Spring-04	90.1	68.7	55.8	74.2	68.2	65.3	172.8	85.0
Summer-04	98.5	65.4	53.0	86.5	91.7	81.7	140.8	88.2
Autumn-04	54.5	56.1	42.4	57.9	52.6	50.7	98.7	59.0
Winter-04	78.8	70.1	38.6	42.3	42.4	45.8	142.0	65.7
Spring-05	75.9	63.9	51.1	52.7	57.7	52.6	149.3	71.9
Summer-05	130.8	99.4	72.6	89.6	96.9	92.6	163.1	106.4
Mean	84.0	72.0	51.4	67.3	67.3	63.4	139.1	
Effect	**Season**	**Lake**	**Season x Lake**					
C.D. (p =0.05)	2.7	2.4	7.2					

as compared to the values recorded in respective seasons of 2003-04. A significant and continuous increase in total hardness was also noted in all seasons from autumns to summers during both years.

As regards the interaction effect of lakes and seasons, the highest total hardness was found in Nainital during spring of 2004 (172.8 mg L^{-1}) while the lowest was noted in Punatal during autumn-2004 (38.6 mg L^{-1}).

4.1.16 Total alkalinity (as HCO_3^-)

The data on seasonal variation in total alkalinity of waters of different lakes are presented in Table 4.16. Total alkalinity in the waters was found only due to bicarbonates.

The values of total alkalinity of waters from different lakes averaged over seasons indicated that the highest total alkalinity was found in Nainital (242.8 mg L^{-1}) followed by Bhimtal (143.5 mg L^{-1}), Naukuchiatal (141.6 mg L^{-1}), Ramtal (115.6 mg L^{-1}), Hanumantal (110.1 mg L^{-1}), Sitatal (105.3 mg L^{-1}) and Punatal (87.1 mg L^{-1}). The averaged values of total alkalinity in Bhimtal and Naukuchiatal and Sitatal and Hanumantal were statistically *at par*.

These values were well within the same range reported by earlier for Indian lakes (Dhamija and Jain, 1995; Rasool *et al.*, 2003; Kudari *et al.*, 2004; Radhika *et al.*, 1999). Considering 200 mg L^{-1} as the maximum value of alkalinity as per the BIS criterion, these waters were safe even for potable use.

The values averaged over lakes revealed that the highest total alkalinity of waters was found during spring 2004 in the first year

Table 4.16. Seasonal variation in alkalinity (mg L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	162.2	156.3	100.6	111.8	123.0	123.0	240.4	145.3
Autumn-03	89.4	128.6	55.9	83.9	89.5	89.4	176.7	101.9
Winter-03	150.9	128.6	89.5	111.8	123.0	117.4	274.0	142.2
Spring-04	162.2	145.4	95.0	111.8	123.0	111.8	296.4	149.4
Summer-04	160.3	152.7	100.6	110.0	119.3	113.7	236.7	141.9
Autumn-04	86.6	131.4	53.1	83.9	95.1	86.7	172.2	101.3
Winter-04	150.9	131.4	86.7	106.2	120.2	117.4	262.8	139.4
Spring-05	164.0	150.9	98.8	113.7	121.1	111.8	257.2	145.4
Summer-05	164.6	149.0	103.7	114.3	126.1	119.3	268.4	149.4
Mean	143.5	141.6	87.1	105.3	115.6	110.1	242.8	
Effect	Season	Lake	Season x Lake					
C.D. (p =0.05)	6.2	5.4	16.3					

however, in second year the highest was noted during summer-2005. The lowest values of total alkalinity in waters were noted during autumns of both years. No significant difference was noted between the averaged values of autumns, winters and springs of 2003-04 and those of 2004-05, respectively. During summer of 2005, a significant increase in total alkalinity was noted as compared to summer of 2004.

As regards the interaction of lakes and seasons, the highest total alkalinity was found in Nainital during spring of 2004 (296.8 mg L^{-1}) while the lowest was noted in Punatal during autumn-2004 (53.1 mg L^{-1}).

4.1.17 Sodium adsorption ratio (SAR)

The data on seasonal variation in sodium adsorption ratio of waters of different lakes are presented in Table 4.17.

The values of SAR of waters from different lakes averaged over seasons indicated that the highest SAR was found in Nainital (1.32) followed by Bhimtal (0.95), Naukuchiatal (0.91), Punatal (0.81), Hanumantal (0.71), Sitatal (0.69) and Ramtal (0.66). The averaged values of SAR in Sitatal and Hanumantal were statistically *at par*.

These results were in good agreement with those obtained by Tiwari (1999) and Patil and Tijare (2001) in various lakes. The values of sodium adsorption ratio indicated that the waters of lakes could be used safely for irrigation purpose.

The values averaged over lakes revealed that the highest SAR value of waters was found during summer-2003 while the lowest values of SAR in waters were noted during autumns of both years. A

Table 4.17. Seasonal variation in sodium adsorption ratio of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	1.17	1.01	0.75	0.81	0.71	0.74	1.70	0.98
Autumn-03	0.91	0.69	0.73	0.62	0.62	0.65	1.24	0.78
Winter-03	0.86	0.84	0.79	0.73	0.69	0.70	1.03	0.81
Spring-04	0.92	0.95	0.83	0.57	0.60	0.69	1.23	0.83
Summer-04	1.03	1.17	0.92	0.66	0.62	0.72	1.61	0.96
Autumn-04	0.90	0.69	0.71	0.58	0.60	0.64	1.19	0.76
Winter-04	0.84	0.88	0.87	0.89	0.81	0.75	1.08	0.88
Spring-05	1.01	0.98	0.87	0.68	0.66	0.77	1.33	0.90
Summer-05	0.90	0.95	0.79	0.65	0.60	0.68	1.50	0.87
Mean	0.95	0.91	0.81	0.69	0.66	0.71	1.32	
Effect	**Season**	**Lake**	**Season x Lake**					
C.D. (p =0.05)	0.03	0.02	0.07					

significant increase was noted between the averaged values of autumns, winters and springs of 2003-04 as compared to the values recorded in respective seasons of 2004-05. During summer of 2004-05, a significant reduction in SAR value was noted as compared to summer of 2003-04.

The interaction between seasons and lakes was also significant. The highest SAR value was found in Nainital during summer of 2003 (1.70) while the lowest was noted in Sitatal during autumn-2004 (0.58).

4.1.18 Residual sodium carbonate (RSC)

The data on seasonal variation in residual sodium carbonate (RSC) of waters of different lakes are presented in Table 4.18.

The values of RSC of waters from different lakes averaged over seasons indicated that the highest RSC value was found in Nainital (1.20 me L^{-1}) followed by Naukuchiatal (0.88 me L^{-1}), Bhimtal (0.67 me L^{-1}), Ramtal (0.55 me L^{-1}) Hanumantal (0.54 me L^{-1}), Punatal (0.40 me L^{-1}), and Sitatal (0.38 me L^{-1}). The averaged values of RSC value in Punatal and Sitatal and Ramtal and Hanumantal were statistically *at par* with each other.

The values of residual sodium carbonate in these lakes were below the tolerance limits of 2 me L^{-1} for irrigation use.

The values averaged over lakes revealed that the highest RSC value of waters was found during winter-2004 (0.97 me L^{-1}) while the lowest value of RSC in waters value was noted during summer-2005 (0.32 me L^{-1}).

Table 4.18. Seasonal variation in residual sodium carbonate (me L^{-1}) of waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	0.67	0.71	0.40	0.06	0.25	0.38	1.14	0.52
Autumn-03	0.39	1.01	0.12	0.35	0.47	0.51	1.09	0.56
Winter-03	0.97	0.58	0.53	0.58	0.86	0.88	1.40	0.83
Spring-04	0.86	1.01	0.44	0.35	0.65	0.53	1.40	0.75
Summer-04	0.66	1.19	0.59	0.07	0.12	0.23	1.06	0.56
Autumn-04	0.33	1.03	0.02	0.22	0.51	0.41	0.85	0.48
Winter-04	0.90	0.75	0.65	0.89	1.12	1.01	1.47	0.97
Spring-05	1.17	1.19	0.60	0.81	0.83	0.78	1.23	0.94
Summer-05	0.08	0.45	0.25	0.08	0.13	0.10	1.14	0.32
Mean	0.67	0.88	0.40	0.38	0.55	0.54	1.20	

Effect	Season	Lake	Season x Lake
C.D. ($p = 0.05$)	0.08	0.07	0.22

The interaction between seasons and lakes was also significant. The highest RSC value was found in Nainital during winter-2004 (1.47 me L^{-1}) while the lowest was noted in Sitatal during summer-2004 (0.07 me L^{-1}).

As regards the seasonal variation in physico-chemical properties of water, different properties like pH, electrical conductivity, alkalinity (HCO_3^-), biological oxygen demand and chemical oxygen demand were maximum during summers while the minimum values were recorded during autumn season. The observed trend could be attributed to the evaporation of water from lakes during summer and subsequent dilution due to precipitation and run-off from the catchment area during rainy season (Bhatt *et al.*, 1999; Radhika *et al.*, 2004). High pH in summer could be a result of increased photosynthesis. A similar effect could also be produced by water evaporation through the loss of half bound CO_2 and precipitation of monocarbonate (Khan and Chowdhary, 1994). Photosynthetic assimilation of dissolved inorganic carbon by planktons could also increase pH (Farrell *et al.*, 1979; Goldman, 1972 and King, 1970).

The alkaline pH and high alkalinity of lake water might be due to the use of some alkaline substances by people for washing of clothes, vehicle and utensils. A wash off from area having carbonate containing minerals might also partly contribute to alkalinity (Paka and Rao, 1997). The higher values of alkalinity indicated the potential susceptibility of these water bodies for eutrophication. Water body with alkalinity values >100mg L^{-1} is considered nutritionally rich (Philipose, 1960; Spence, 1964) and on the basis of this observation most of lakes of Nainital could be considered prone to eutrophication problem.

Pre-monsoon (summer) maxima and monsoon (rainy) minima of conductivity values might be due to increased rate of evaporation leading to high concentration of salts in summer while dilution due to precipitation in rainy season lowered the values (Radhika *et al.,* 2004).

Low dissolved oxygen during summer might also be due to higher microbiological activities. Decomposition of organic matter might be an important factor in consumption of dissolved oxygen, as more vigorous deposition could be likely during warm weather which also witnessed increased inflow of tourists (Badge and Verma, 1985; Singh and Sahai, 1979). The phenomenon of re-oxygenation of water during monsoon might be due to circulation and mixing by inflow after monsoon rains (Hannan, 1978).

Higher concentrations of cations and anions during summers might be due to the increased anthropogenic activities coupled with setting of particulates at the bottom due to the restricted flow of water by the sluice. In summers, the temperature was also raised, which enhanced the release nutrients from sediments through bacterial growth (Saha *et al.,* 2001).

Waters rich in bicarbonates are also rich in calcium as well. It is due to the conversion of insoluble $CaCO_3$ to soluble calcium bicarbonate in the presence of CO_2. Higher values of hardness in lakes may be due to addition of calcium and magnesium salts from detergents as they are used for washing and bathing (Radhika *et al.,* 2004). Higher values of hardness in summer might be due to high temperature, which increased concentration of salts by excessive evaporation. The contents released from dead mollusc shells might also increase the concentration of total hardness (Khan and Chowdhary, 1994).

Higher values of sulphate might be the result of the release of sulphates due to biological activity (bacterial oxidation) from organically bound sulphur in the waters. Household detergents, which enter the domestic sewage, might also be the reason for the presence of sulphate in the waters of some lakes. Higher concentration of chloride in waters during summer season might be due to inflow of animal wastes (Rasool *et al.*, 2003).

The concentration of chloride was considerably higher and fluctuated more irregularly in the first year samplings while in the second year it changed temporally very little. These variations in the first year might be associated with the hydrology of the basin, as chlorides are very inert chemically and biologically in the hydrosphere and metabolic utilization does not cause significant variations in the spatial and seasonal distribution of the ion within a lake (Wetzel 1975).

As regards the various physico-chemical parameters and concentrations of cations and anions, Nainital was the most polluted among all lakes investigated. The poor water quality of Nainital might be due to heavy tourist load, motor vehicles, construction activities, inflow of the sewage water, monsoon drainage from the catchment area, accumulation of dead organic matter and clay etc. while Bhimtal, Naukuchiatal, Sitatal, Ramtal, Hanumantal and Punatal were relatively less disturbed by tourists.

4.1.19 Total bacterial counts and most probable number (MPN)

The data on seasonal variation in total bacterial counts and most probable number of microbes in waters of different lakes are presented in Table 4.19.

The values of total bacterial counts in waters from different lakes averaged over seasons indicated that the highest total bacterial counts was found in Nainital (1885) followed by Hanumantal (1608), Sitatal (1523), Punatal (1429), Naukuchiatal (1316), Ramtal (1130) and Bhimtal (803). The averaged values of total bacterial counts, in Naukuchiatal and Punatal; Punatal and Sitatal and Sitatal and Hanumantal were statistically *at par.*

These values were in the same range reported by earlier for Indian lakes (Kumaresan and Bagavathiraj, 1996). Considering 1 x 10^4 per ml as the desirable range of total bacterial count as per the USPH criterion, these waters were safe even for potable use.

On the mean value basis, the total bacterial counts in waters during summers were significantly higher than during winters in both years.

The interaction between seasons and lakes was also significant. The highest value of total bacterial counts was found in Nainital during

Table 4.19. Seasonal variation in total bacterial count and most probable number (MPN) in waters from different lakes

Seasons / Lakes	Total bacterial count per mL					Most probable number (MPN) per 100 mL				
	Winter-03	Summer-04	Winter-04	Summer-05	Mean	Winter-03	Summer-04	Winter-04	Summer-05	Mean
Bhimtal	805	956	745	705	803	85	190	131	141	137
Naukuchiatal	1087	755	1611	1812	1316	50	131	11	91	71
Punatal	1752	1208	1349	1409	1429	26	76	7	54	41
Sitatal	1470	2577	1087	956	1523	13	12	8	7	10
Ramtal	1208	1188	966	1158	1130	4	37	18	17	19
Hanumantal	1460	2013	1450	1510	1608	7	46	8	20	20
Nainital	1470	1711	1601	2758	1885	170	984	98	979	558
Mean	1322	1487	1258	1473		51	211	40	187	
Effect	Season	Lake	Season x Lake			Season	Lake	Season x Lake		
C.D. (p =0.05)	99	131	263			20	27	54		

summer-2005 (2758) while the lowest was noted in Bhimtal during winter-2003 (705).

The values of most probable number in waters from different lakes averaged over seasons indicated that the highest MPN was found in Nainital (558) followed by Bhimtal (137), Naukuchiatal (71), Punatal (41), Hanumantal (20), Ramtal (19) and Sitatal (10). The averaged values of MPN in Punatal, Ramtal and Hanumantal and Sitatal, Ramtal and Hanumantal were statistically *at par.*

The results were also in good agreement with the observations recorded by Nair and Shrivastava (2003). The values of most probable number fell within the tolerance limit of 500 for drinking purpose given by BIS.

On the mean value basis, the MPN in waters were significantly higher during summers than during winters in both years.

As regards the interaction between seasons and lakes, the highest MPN was found in Nainital during summer-2004 (984) while the lowest value was noted in Ramtal during winter-2003 (4).

4.2 Heavy metal concentration in waters

4.2.1 Chromium (Cr)

The data on seasonal variation in Cr content in waters of different lakes are presented in Table 4.20 & Fig. 1.

The values averages over seasons for different lakes indicated that the highest Cr concentration was found in Naukuchiatal (2.11 μg L^{-1}), Punatal (1.95 μg L^{-1}), Bhimtal (1.94 μg L^{-1}), Nainital (1.93 μg L^{-1}),

Table 4.20. Seasonal variation of Cr content ($\mu g\ L^{-1}$) in waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	2.02	2.13	2.02	0.46	0.51	0.45	2.00	1.37
Autumn-03	1.70	1.88	1.74	0.29	0.33	0.30	1.69	1.13
Winter-03	1.86	2.03	1.89	0.41	0.49	0.41	1.87	1.28
Spring-04	1.96	2.06	1.93	0.48	0.54	0.47	1.97	1.34
Summer-04	2.08	2.27	2.09	0.50	0.57	0.49	2.06	1.44
Autumn-04	1.72	1.92	1.74	0.32	0.35	0.31	1.74	1.16
Winter-04	1.92	2.08	1.98	0.45	0.55	0.45	1.92	1.34
Spring-05	2.03	2.24	2.05	0.52	0.65	0.52	2.00	1.43
Summer-05	2.13	2.39	2.11	0.57	0.70	0.54	2.13	1.51
Mean	1.94	2.11	1.95	0.45	0.52	0.44	1.93	
Effect	**Season**	**Lake**	**Season x Lake**					
C.D. (p =0.05)	0.05	0.04	0.12					

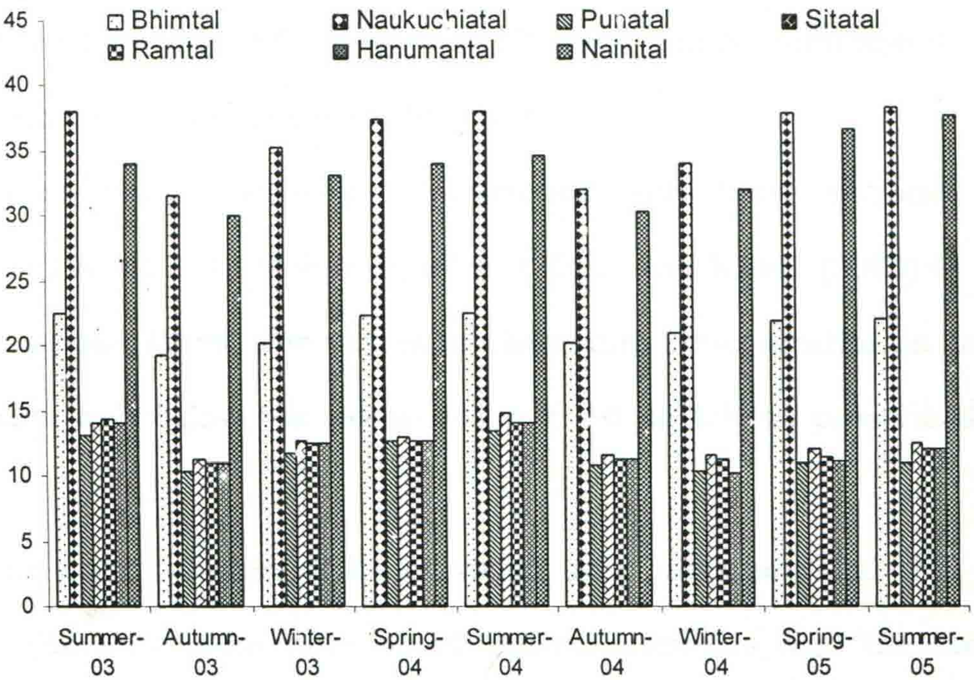

Fig. 4.1 Seasonal variation in Cr content (µg L^{-1}) in waters from different lakes

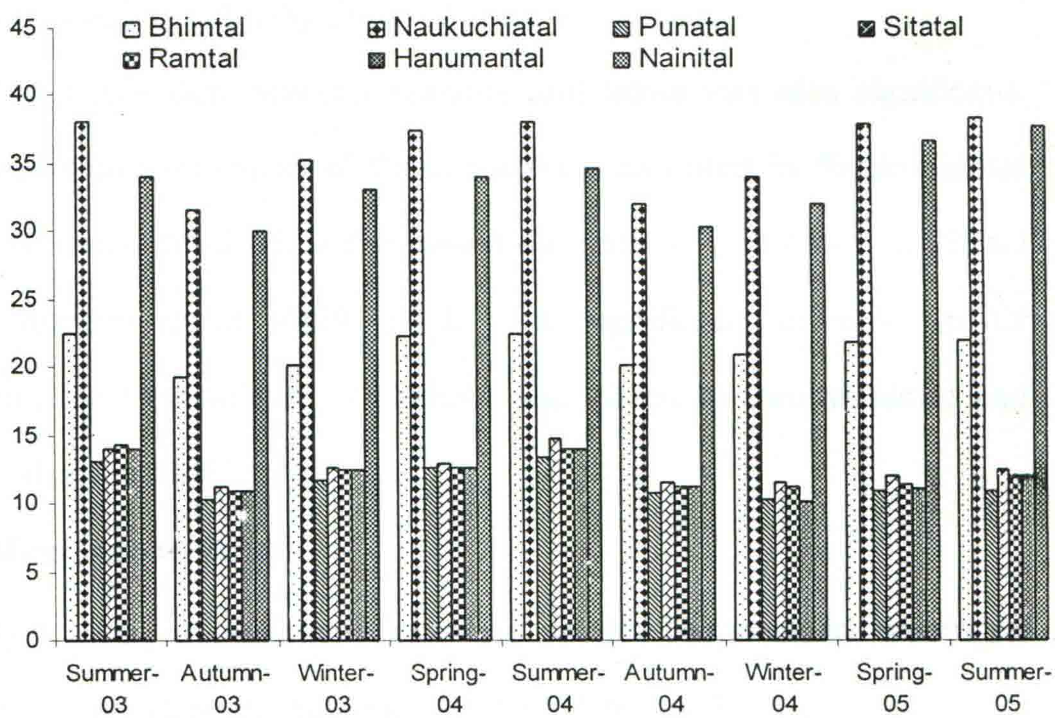

Fig. 4.2 Seasonal variation in Mn content (µg L^{-1}) in waters from different lakes

Ramtal (0.52 μg L^{-1}), Sitatal (0.45 μg L^{-1}) and Hanumantal (0.44 μg L^{-1}). The averaged content of Cr in Bhimtal, Punatal and Nainital and Sitatal and Hanumantal were statistically *at par.*

These results were in concurrence with those obtained by Kaushik *et al.* (1999); Mohanraj *et al.* (2000) and Khalil (2000) in the case of various lakes. The values of chromium concentration in these lakes were well below the tolerance limit (10 μg L^{-1}) as prescribed by WHO.

The concentration of Cr averaged over lakes revealed that the highest concentrations were noted during summers and the lowest values were during autumns in both years. A significant increase in Cr content was noted during winters after autumns of both years while the values of Cr content from winters to springs during 2003-04 and springs to summers during 2004-05 were increased.

The interaction between seasons and lakes was also significant. The highest concentration of Cr in waters was noted in Naukuchiatal during summer–2005 while the lowest Cr content was noted in Sitatal during autumn–2003 (0.29 μg L^{-1}). A significant increase in Cr concentration from spring to summer was noted in Naukuchiatal and Nainital during 2005.

4.2.2 Manganese (Mn)

The data on seasonal variation in Mn content in waters of different lakes are represented in Table 4.21 & Fig. 2.

Seasonally averaged values for different lakes indicated that the highest concentration of Mn was found in Naukuchiatal (35.9 μg L^{-1})

Table 4.21. Seasonal variation of Mn content (μg L^{-1}) in waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	22.6	38.0	13.2	14.0	14.3	14.1	34.1	21.5
Autumn-03	19.2	31.6	10.3	11.2	10.9	10.9	30.1	17.7
Winter-03	20.2	35.3	11.3	12.7	12.5	12.5	33.1	19.7
Spring-04	22.4	37.4	12.6	13.0	12.6	12.7	34.0	20.6
Summer-04	22.6	38.1	13.4	14.8	14.1	14.1	34.7	21.7
Autumn-04	20.2	32.0	10.8	11.5	11.2	11.2	30.4	18.2
Winter-04	20.9	34.0	10.4	11.6	11.3	10.2	32.1	18.6
Spring-05	21.9	37.9	10.9	12.0	11.4	11.1	36.6	20.3
Summer-05	22.0	38.3	10.9	12.5	12.0	12.1	37.7	20.8
Mean	21.3	35.9	11.6	12.6	12.2	12.1	33.6	

Effect	Season	Lake	Season x Lake
C.D. ($p = 0.05$)	0.4	0.3	0.9

followed by Nainital (33.6 μg L^{-1}), Bhimtal (21.3 μg L^{-1}), Sitatal (12.6 μg L^{-1}), Ramtal (12.2 μg L^{-1}), Hanumantal (12.1 μg L^{-1}) and Punatal (11.6 μg L^{-1}). The averaged content of Mn in Ramtal and Hanumantal were statistical *at par.*

These values were in the same range as reported earlier for various lakes (Francis, 1997; by Kaushik *et al.*, 1999; Mohanraj *et al.*, 2000). Considering 100 μg L^{-1} as the maximum tolerance value of Mn as per the BIS criterion, these waters were safe even for potable use.

The Mn content averaged over lakes ranged from 21.7 μg L^{-1} (summer– 2004) to 17.7 μg L^{-1} (autumn–2003). After autumn–2003, a significant increase was noted up to summer–2004. The values of Mn content also revealed that the highest concentration was recorded during summers while the lowest values were recorded during autumns of both years.

The interaction effect between seasons and lakes was also significant. The highest Mn concentration was noted in Naukuchiatal during summer–2005 (38.3 μg L^{-1}) while the lowest Mn content was noted in Punatal during autumn–2005 (10.3 μg L^{-1}). A significant reduction in Mn content was noted in Hanumantal during winter–2004 after autumn–2004, while a significant increase in Mn content was registered during the similar period in the case of Naukuchiatal.

4.2.3 Iron (Fe)

The data on seasonal variation in Fe content in waters of different lakes are presented in Table 4.22 & Fig. 3.

Table 4.22. Seasonal variation of Fe content (μg L^{-1}) in waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	730	1407	745	900	902	1062	712	923
Autumn-03	432	1008	469	608	630	624	521	613
Winter-03	601	1277	608	746	731	837	653	779
Spring-04	731	1313	715	824	817	957	828	884
Summer-04	774	1352	829	861	858	971	866	930
Autumn-04	431	1029	502	614	633	647	542	628
Winter-04	615	1305	714	750	739	811	669	801
Spring-05	657	1211	874	864	889	961	736	885
Summer-05	740	908	871	800	818	857	788	826
Mean	635	1201	703	774	780	858	702	
Effect	**Season**	**Lake**	**Season x Lake**					
C.D. (p = 0.05)	77	68	204					

The values averaged over seasons for different lakes indicated that the highest iron content was found in waters of Naukuchiatal (120 μg L^{-1}) followed by Hanumantal (858 μg L^{-1}), Ramtal (780 μg L^{-1}), Sitatal (774 μg L^{-1}), Punatal (703 μg L^{-1}), Nainital (702 μg L^{-1}) and Bhimtal (635 μg L^{-1}). The averaged content of iron in Sitatal and Ramtal, Punatal and Nainital and, Bhimtal and Nainital were statistically *at par.*

A similar range of values was also reported earlier by several workers (Kaushik *et al.*, 1999; Khalil, 2000; Mohanraj *et al.*, 2000). The values of iron concentration in waters of all lakes were more than highest desirable limit of 300 μg L^{-1} but remained below the maximum permissible limit of 1000 μg L^{-1} (WHO, 1988).

The concentration of iron averaged over lakes revealed that the highest concentration was recorded during summers while the lowest values were recorded during autumns in both years.

The interaction between seasons and lakes was also significant. The highest Fe content in waters was recorded in Naukuchiatal during summer 2003 (1407 μg L^{-1}) while the lowest Fe content was noted in Bhimtal during autumn 2004 (431 μg L^{-1}).

4.2.4 Nickel (Ni)

The data on seasonal variation in Ni content in waters of different lake are presented in Table 4.23 & Fig. 4.

The values averaged over seasons for different lakes revealed that the highest Ni content was found in waters of Nainital (5.0 μg L^{-1}) while Bhimtal, Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal contained 2.2, 2.3, 2.4, 2.3 and 2.3 μg L^{-1}, respectively. The average

Table 4.23. Seasonal variation of Ni content ($\mu g\ L^{-1}$) in waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	2.6	2.5	2.5	2.5	2.6	2.4	6.1	3.0
Autumn-03	1.3	1.1	1.2	1.3	1.2	1.2	3.2	1.5
Winter-03	1.8	2.1	1.8	2.3	1.8	1.9	4.0	2.2
Spring-04	2.2	2.6	2.6	2.8	2.3	2.8	5.2	2.9
Summer-04	2.7	3.2	3.0	3.2	3.2	3.0	6.3	3.5
Autumn-04	1.0	1.4	1.3	1.4	1.5	1.4	3.3	1.6
Winter-04	1.9	2.0	2.2	2.0	2.0	1.9	4.9	2.4
Spring-05	2.8	2.9	2.9	2.6	2.7	2.8	5.7	3.2
Summer-05	3.2	3.5	3.3	3.4	3.5	3.3	6.6	3.8
Mean	2.2	2.4	2.3	2.4	2.3	2.3	5.0	
Effect	Season	Lake	Season x Lake					
C.D. (p =0.05)	0.2	0.2	0.6					

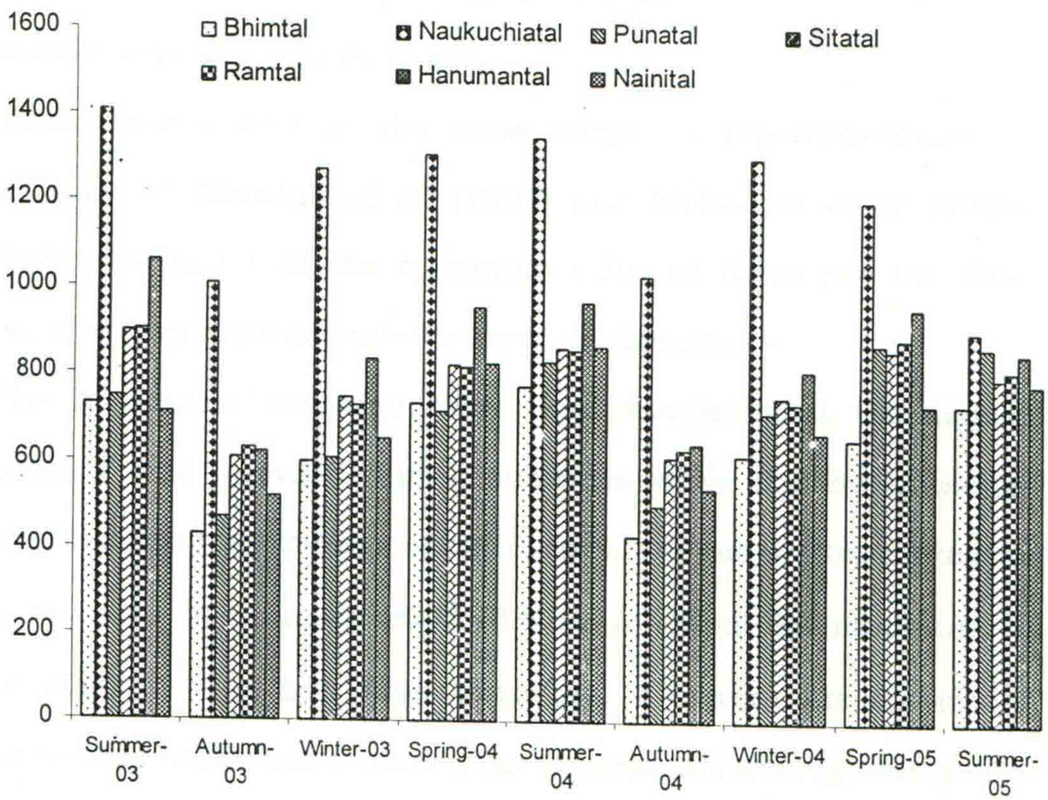

Fig. 4.3 Seasonal variation in Fe content ($\mu g\ L^{-1}$) in waters from different lakes

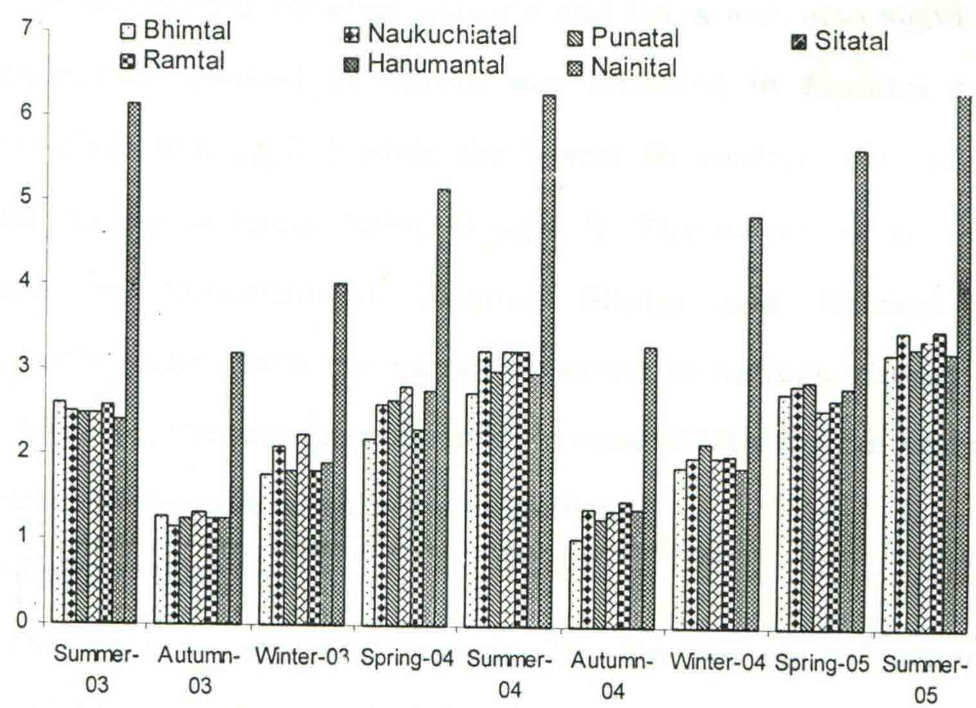

Fig. 4.4 Seasonal variation in Ni content ($\mu g\ L^{-1}$) in waters from different lakes

content of Ni in Bhimtal, Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par*.

These values were in the same range as reported earlier for various lakes by Kaushik *et al.* (1999) and Mohanraj *et al.* (2000). Considering 20 μg L^{-1} as the maximum value of Ni as per the WHO criterion, these waters were safe for even potable use.

The Ni content averaged over lakes revealed that the highest concentration was recorded during summers while the lowest values were recorded during autumns of both years. The maximum content of Ni was recorded in summer 2005 (3.8 μg L^{-1}) and the minimum in autumn 2003 (1.5 μg L^{-1}). After autumns, a continuous significant increase in Ni content was recorded up to summers during both years. The values of Ni in winter, spring and summer of 2004-05 were significantly higher than the values observed in winter, spring seasons respective 2003-04.

The interaction between seasons and lakes was also significant. The highest Ni content in waters was recorded in Nainital during summer-2005 (6.6 μg L^{-1}) while the lowest Ni content was noted in Bhimtal during autumn 2004(1.0 μg L^{-1}). The values of Ni during summers in Naukuchiatal, Ramtal, Sitatal and Nainitai were significantly higher than the values observed in springs, during both years, however, the more are observed in case of Sitatal from spring 04 to summer 04 was statistically non- significant.

4.2.5 Copper (Cu)

The data on seasonal variation in Cu content in waters of different lakes are presented in Table 4.24 & Fig. 5.

Table 4.24. Seasonal variation of Cu content ($\mu g\ L^{-1}$) in waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	10.9	11.5	8.4	8.4	8.6	8.7	10.6	9.5
Autumn-03	8.6	10.5	5.9	5.3	5.3	5.5	6.4	6.8
Winter-03	9.2	10.8	6.1	5.8	5.9	6.2	6.8	7.2
Spring-04	9.7	11.2	6.3	6.3	6.0	6.2	7.3	7.6
Summer-04	10.9	12.1	6.5	7.1	6.6	6.5	9.0	8.4
Autumn-04	8.4	10.6	5.8	5.5	5.5	5.6	7.3	6.9
Winter-04	9.0	10.8	6.3	6.2	6.2	6.1	7.8	7.5
Spring-05	9.0	11.5	6.5	6.6	6.6	6.5	8.3	7.9
Summer-05	9.3	12.1	7.2	7.2	7.5	8.6	9.2	7.0
Mean	9.5	11.24	6.5	6.4	6.5	6.5	8.1	

Effect	Season	Lake	Season x Lake
C.D. ($p = 0.05$)	0.2	0.2	0.5

The values averaged over seasons for different lakes indicated that Naukuchiatal had the highest concentration of Cu in the waters (11.24 μg L^{-1}), followed by Bhimtal (9.5μg L^{-1}), Nainital (8.1μg L^{-1}) and Punatal, Ramtal, Hanumantal (6.5 μg L^{-1}) and Sitatal (6.4 μg L^{-1}). The averaged values of Cu content in Punatal, Ramtal, Hanumantal and Sitatal were statistically *at par* with each other.

These results are in good agreement with those reported for various lakes by Jain and Salman (1995), Francis (1997), Kaushik *et al.* (1999), Mohanraj *et al.* (2000) and Patil *et al.* (2004). The values of copper concentration in these lakes were well below the tolerance limit (50 μg L^{-1}) as prescribed by WHO.

The concentration of Cu averaged over lakes revealed that the highest concentrations were recorded during summers while the lowest values were during autumns of both years. The maximum content of Cu was recorded in summer–2003 (9.5 μg L^{-1}) and minimum in autumn–2003 (6.8 μg L^{-1}). After autumns, there was a continuous significant increase in Cu content was noted up to summers during both years. The Cu contents in winter, spring and summer of 2004-05 were statistically significantly higher than those recorded in winter, spring and summer of 2003-04, respectively.

The interaction between season and lakes was also significant. The highest Cu content in waters was recorded in Naukuchiatal during summers of 2004 and 2005 (12.1 μg L^{-1}) while the lowest Cu content was noted in Sitatal and Ramtal during autumn – 2003 (5.3 μg L^{-1}). The values of Cu in summer 2005 for all lakes except Bhimtal were significantly higher than the values of springs- 2005.

4.2.6 Zinc (Zn)

The data on seasonal variation in Zn content in waters of different lakes are presented in Table 4.25 & Fig. 6.

The values averaged over seasons for different lakes indicated that the highest zinc content was found in waters of Nainital (122.8 μg L^{-1}) followed by Bhimtal (69.5 μg L^{-1}), Naukuchiatal (47.3 μg L^{-1}), Punatal (36.7 μg L^{-1}), Sitatal (34.0 μg L^{-1}), Hanumantal (33.9 μg L^{-1}) and Ramtal (32.5 μg L^{-1}). The averaged contents of Zn in Sitatal and Hanumantal were statistically *at par*.

These values were well within the same range reported earlier for various other lakes by several workers (Jain and Salman, 1995; Francis, 1997; by Kaushik *et al.*, 1999; Mohanraj *et al.*, 2000; Patil *et al.*, 2004). Considering 3000 μg L^{-1} as the maximum value of Zn as the WHO criterion, these waters were safe even for potable use.

The concentration of Zn averaged over lakes revealed that the highest concentration was recorded during summer while the lowest values were noted during autumns in both years. The values ranged from 32.9 μg L^{-1} to 70.9 μg L^{-1}. After autumns a continuous significant increase in zinc content was noted up to summers during both years. The values of Zn concentration in autumns, winter and spring of 2004-05 were significantly higher than those observed in respective seasons of 2003-04.

The interaction between seasons and lakes was also significant. The highest Zn concentration in water was recorded in Nainital during summer–2004 (166.3 μg L^{-1}) while the lowest Zn content was noted in Punatal during autumn–2003 (12.6 μg L^{-1}).

Table 4.25. Seasonal variation of Zn content ($\mu g\ L^{-1}$) in waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	76.5	54.3	43.0	45.5	43.4	46.3	119.1	61.2
Autumn-03	41.0	24.2	12.6	18.9	20.6	25.7	87.2	32.9
Winter-03	66.1	44.8	33.1	23.6	22.7	23.6	94.0	44.0
Spring-04	75.7	56.0	43.1	38.7	34.6	30.8	135.1	59.1
Summer-04	87.5	57.1	47.9	46.7	42.7	48.2	166.3	70.9
Autumn-04	43.3	25.2	13.4	20.5	21.3	26.5	97.3	35.4
Winter-04	74.9	49.9	34.8	25.3	23.7	24.6	101.3	47.8
Spring-05	79.1	57.0	48.9	40.6	37.2	34.7	146.9	63.5
Summer-05	81.6	57.3	53.4	46.1	46.7	44.6	157.7	69.6
Mean	69.5	47.3	36.7	34.0	32.5	33.9	122.8	
Effect	Season	Lake	Season x Lake					
C.D. ($p = 0.05$)	1.2	1.1	3.3					

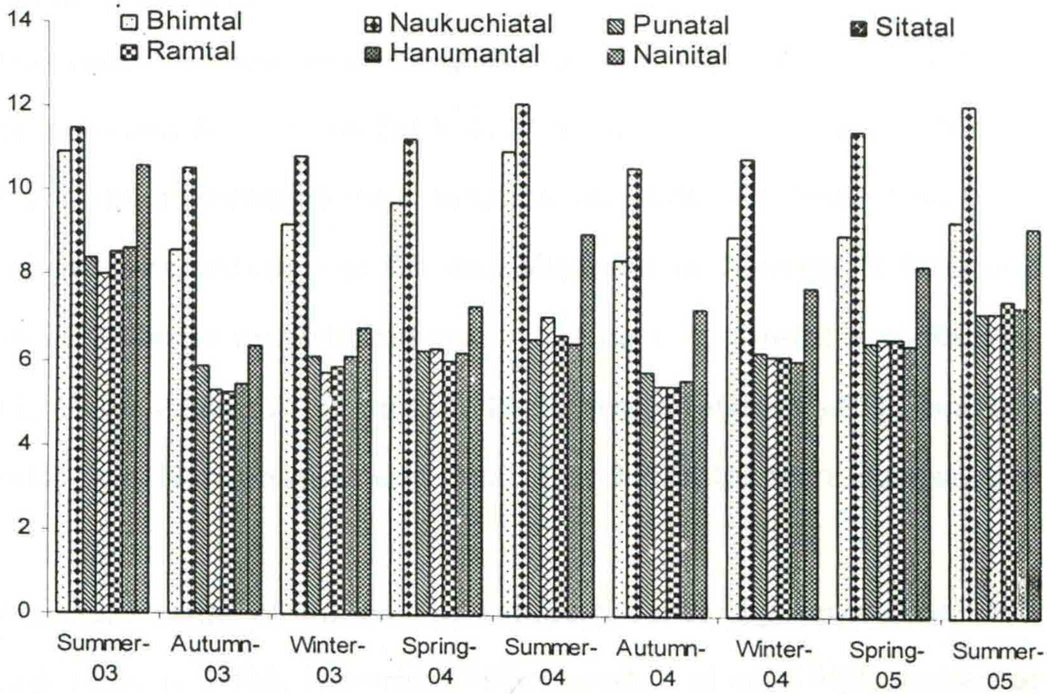

Fig. 4.5 Seasonal variation in Cu content (μg L^{-1}) in waters from different lakes

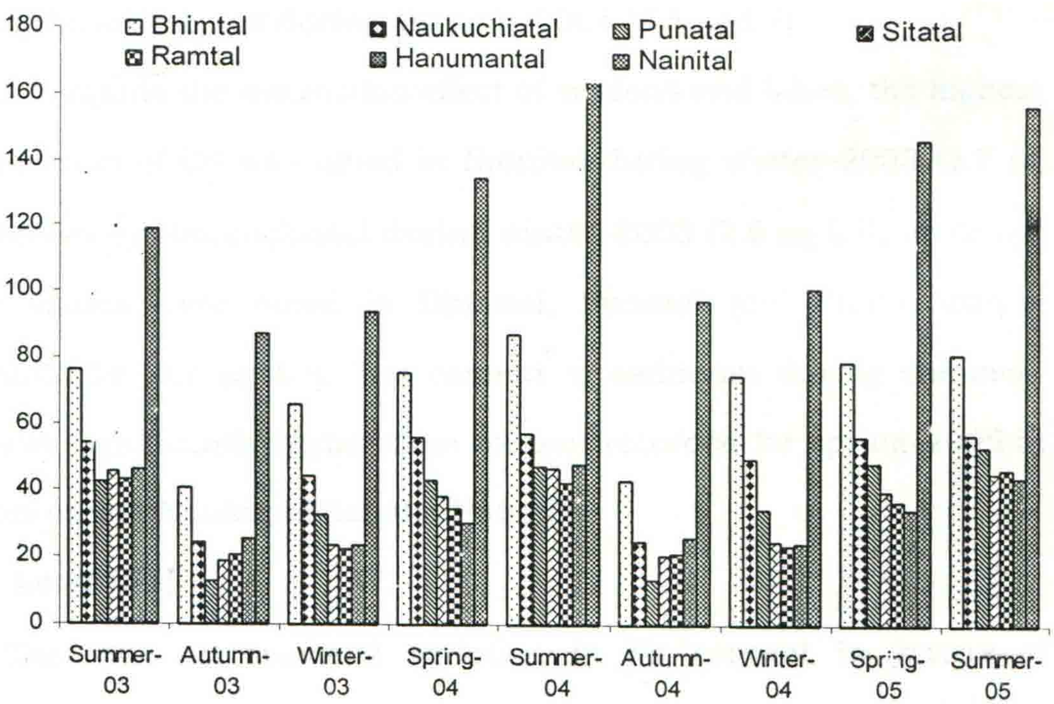

Fig. 4.6 Seasonal variation in Zn content (μg L^{-1}) in waters from different lakes

4.2.7 Cadmium (Cd)

The data on seasonal variation in Cd content in waters of different lakes are depicted in Table 4.27 & Fig. 7.

The values averaged over seasons for different lakes indicated that highest concentration of Cd was obtained in Nainital (1.8 µg L^{-1}) followed by Bhimtal and Hanumantal (1.3 µg L^{-1}), Sitatal and Ramtal (1.2 µg L^{-1}) and Punatal (1.1 µg L^{-1}). The averaged values of Cd content in Bhimtal and Hanumantal and Sitatal and Ramtal were statistically *at par.*

A similar range of values was reported earlier by several workers (Jain and Salman, 1995; Francis, 1997; Kaushik *et al.*, 1999; Mohanraj *et al.*, 2000). The values of Cd concentration in waters of all lakes were less than the highest desirable limit of 3 µg L^{-1} (WHO, 1988).

The highest Cd content was noted during winter–2003 (1.8 µg L^{-1}) and the lowest was during autumn–2004 (0.8 µg L^{-1}).

As regards the interaction effect of seasons and lakes, the highest concentration of Cd was noted in Nainital during winter–2003 (2.7 µg L^{-1}) followed by Naukuchiatal during winter–2003 (2.6 µg L^{-1}), while the lowest values were noted in Bhimtal, Punatal and Sitatal during autumn-2004 (0.7 µg L^{-1}). The content of cadmium during summer–2005 was significantly higher than content recorded for spring–2005 in all lakes except Naukuchiatal and Punatal.

4.2.8 Lead (Pb)

The data on seasonal variation in Pb content in waters of different lakes are presented in Table 4.28 & Fig. 8. Seasonally averaged values for different lakes indicated that the highest concentration Pb was obtained in waters of Nainital (21.8 µg L^{-1})

Table 4.26. Seasonal variation of Cd content ($\mu g\ L^{-1}$) in waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	1.2	2.2	1.3	1.3	1.3	1.3	1.8	1.5
Autumn-03	0.8	1.4	0.7	1.0	1.1	1.4	1.4	1.1
Winter-03	1.9	2.6	1.5	1.2	1.2	1.3	2.7	1.8
Spring-04	1.3	1.3	0.8	1.1	1.0	1.1	2.2	1.3
Summer-04	1.2	1.7	0.9	1.0	1.0	1.5	2.1	1.3
Autumn-04	0.7	1.0	0.7	0.7	0.8	0.8	1.0	0.8
Winter-04	1.3	1.6	1.1	1.2	1.3	1.2	1.4	1.3
Spring-05	1.5	1.8	1.4	1.4	1.5	1.4	1.7	1.5
Summer-05	1.8	1.8	1.4	1.7	1.8	1.7	2.1	1.7
Mean	1.3	1.7	1.1	1.2	1.2	1.3	1.8	
Effect	**Season**	**Lake**	**Season x Lake**					
C.D. (p =0.05)	0.1	0.1	0.2					

followed by Naukuchiatal (21.8 μg L^{-1}), Bhimtal (11.3 μg L^{-1}), Punatal (10.8 μg L^{-1}), Hanumantal (7.18 μg L^{-1}), Sitatal (7.5 μg L^{-1}) and Ramtal (6.4 μg L^{-1}). The averaged values of Pb in all lakes were statistically different from each other.

These values were in the same range as reported earlier for various lakes by several lakes (Jain and Salman, 1995; Kaushik *et al.*, 1999; Khalil, 2000; Mohanraj *et al.*, 2000). Considering 50 μg L^{-1} as the maximum value of Pb as per the BIS criterion, these waters were safe even for potable use.

The concentration of Pb averaged over lakes revealed that the highest concentration was recorded during summers and the lowest values during autumns of both years. After monsoons, a continuous significant increase in Pb content was noted up to sommers during both years. The values of Pb concentration in autumns, winters and summers of both years were statistically *at par*. The value of Pb in spring–2004 was significantly higher than the value in spring–2005.

The interaction between seasons and lakes was also significant. The highest Pb content in lake waters was noted in Nainital during summer–2004 (27.1 μg L^{-1}) and the lowest recorded for Ramtal during autumn–2004 (3.0 μg L^{-1}). The values of Pb content in spring–2004 and summer–2004 were statistically *at par* with each other for all lakes except for Punatal, where the content registered a significant measure. A significant reduction in Pb content for Sitatal was noted during summer-2005 as compared to spring 2005.

Table 4.27. Seasonal variation of Pb content (μg L^{-1}) in waters from different lakes

Seasons	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nainital	Mean
Summer-03	12.7	18.1	12.0	9.0	8.1	8.5	26.5	13.6
Autumn-03	9.0	12.1	8.6	4.7	4.1	4.4	15.0	8.3
Winter-03	10.2	17	10.8	6.9	6.5	6.8	19.6	11.1
Spring-04	12.4	18.6	11.5	7.8	7.3	7.7	27.0	13.2
Summer-04	12.8	18.5	12.1	7.8	7.8	8.2	27.1	13.5
Autumn-04	9.4	12.1	8.7	4.6	3.9	4.6	15.0	8.3
Winter-04	10.6	16.8	10.5	8.7	5.9	7.5	19.5	11.4
Spring-05	11.3	18.4	11.3	9.1	6.2	8.4	20.3	12.2
Summer-05	13.1	18.7	12.2	8.4	7.9	8.4	25.8	13.5
Mean	11.3	16.7	10.9	7.5	6.4	7.17	21.8	
Effect	Season	Lake	Season x Lake					
C.D. ($p = 0.05$)	0.3	0.3	0.6					

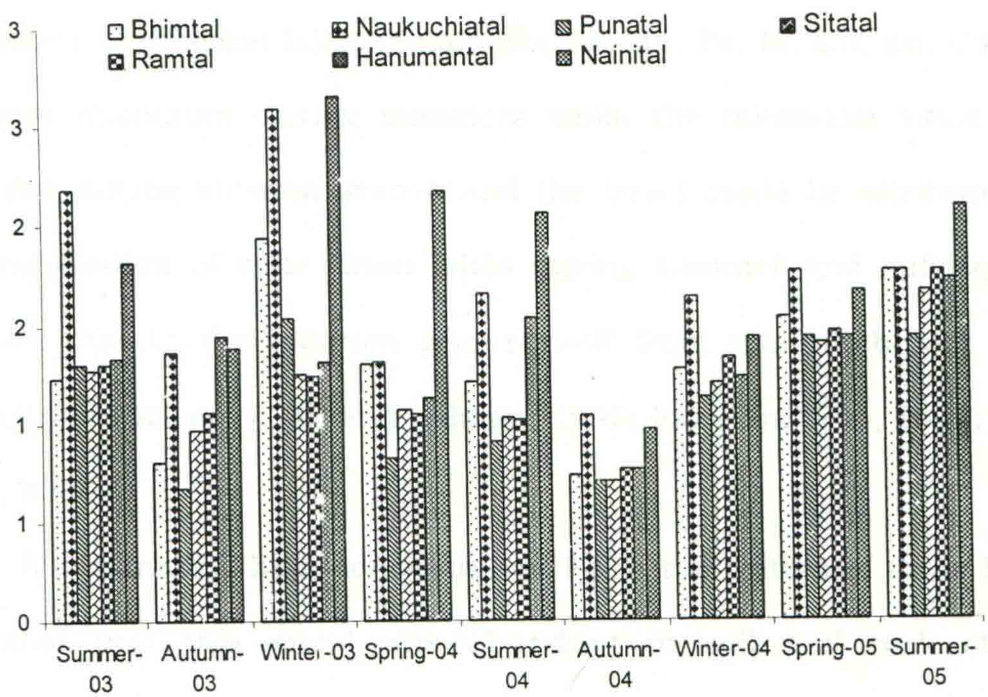

Fig. 4.7 Seasonal variation in Cd content (μg L^{-1}) in waters from different lakes

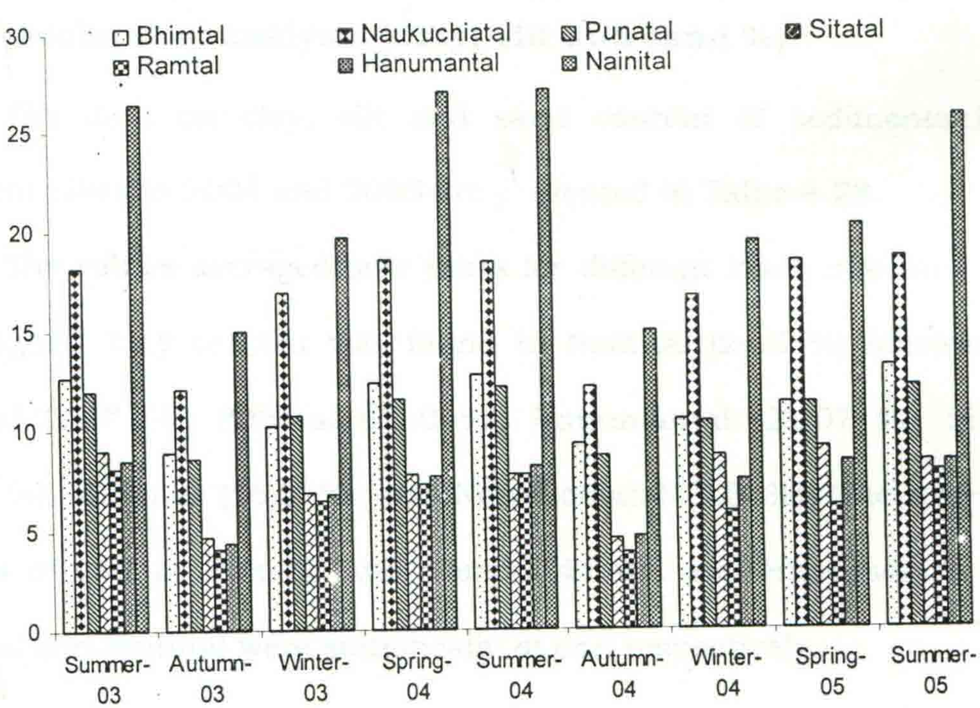

Fig. 4.8 Seasonal variation in Pb content (μg L^{-1}) in waters from different lakes

As regards the effect of season on heavy metal concentration in the waters of different lakes metals like Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb were maximum during summers while the minimum value was recorded during autumn season and the trend could be attributed to the evaporation of water from lakes during summer and subsequent dilution due to precipitation and run-off from the catchment area during rainy season (Jain and Salman, 1995; Paka and Rao, 1997; Patil *et al.*, 2004).

A remarkably high concentration Fe in the waters of these lakes indicated that this metal was abundant in soil and rock of the catchment area from where the water reaches these lakes.

4.3 Physico-chemical properties of sediments from different lakes

4.3.1 Mechanical analysis (Clay, silt and sand %)

The data on clay, silt and sand content of sediments from different lakes in 2004 and 2005 are presented in Table-4.28.

The values averaged over years for different lakes indicated that the highest clay content was found in Nainital (24.5 %) followed by Ramtal (23.7 %), Punatal (23.0 %), Hanumantal (21.07 %), Sitatal (20.7 %), Bhimtal (16.2 %) and Naukuchiatal (9.3 %). The averaged values of clay in Punatal and Ramtal, Sitatal and Hanumantal and, Ramtal and Nainital were statistically *at par*, respectively.

The clay content averaged over lakes showed that clay content in both years did not vary.

The interaction between lakes and years was also statistically non-significant.

The silt content values averaged over year for different lakes revealed that the silt content varied from 2.2 % (in Nainital) to 5.5 % (in Bhimtal) whereas, silt contents in Naukuchiatal, Sitatal, Punatal, Ramtal and Hanumantal were found to be 3.5, 3.3, 2.7, 2.7 and 2.5 %, respectively (Table 4.28).

The average values of silt in Naukuchiatal and Sitatal, Punatal, Sitatal and Ramtal and, Hanumantal and Nainital were statistically *at par,* respectively.

The silt content averaged over lakes revealed there was no significant difference between both years.

The interaction between years and lakes was also statistically non- significant.

Yearly averaged values of sand content from different lakes indicated that the highest sand content was found in Naukuchiatal (87.2 %) followed by Bhimtal (78.3 %), Punatal (74.3 %), Hanumantal (76.5 %), Sitatal (76.0 %), Ramtal (73.7 %) and Nainital (73.3 %) (Table-4.28). The averaged values of sand in Punatal, Ramtal and Nainital and, Sitatal and Hanumantal were statistically *at par,* respectively.

As regards the effect of years, there was no significant difference in sand content between 2004 and 2005.

The interaction between lakes and years was also statistically not significant.

Table 4.28. Mechanical analysis of the sediments from different lakes

Year / Lake	Clay (%)			Silt (%)			Sand (%)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	16.0	16.3	16.2	5.7	5.3	5.5	78.3	78.3	78.3
Naukuchiatal	9.0	9.7	9.3	3.3	3.7	3.5	87.7	86.7	87.2
Punatal	23.3	22.7	23.0	2.7	2.7	2.7	74.0	74.7	74.3
Sitatal	20.7	20.7	20.7	3.3	3.3	3.3	76.0	76.0	76.0
Ramtal	24.3	23.0	23.7	2.3	3.0	2.7	73.3	74.0	73.7
Hanumantal	20.3	21.7	21.0	2.7	2.3	2.5	77.0	76.0	76.5
Nainital	24.7	24.3	24.5	2.0	2.3	2.2	73.3	73.3	73.3
Mean	19.8	19.8		3.1	3.2	3.2	77.1	77.0	
Effect	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L
CD (p=0.05)	ns	1.0	ns	ns	0.7	ns	ns	1.3	ns

High sand contents, medium clay content and low silt contents were found in the sediments of lakes. This reflected that coarser particles also enter these water bodies through eroson/landslides.

4.3.2 pH

The data on the pH of sediments (1:2, sediments:water ratio) from different lakes in 2004 and 2005are presented in Table 4.29.

Yearly averaged pH values for different lakes indicated that the highest pH was found in Nainital (8.89) followed by Bhimtal (8.81), Ramtal (8.11), Hanumantal (8.10), Sitatal (8.09), Punatal (7.98) and Naukuchiatal. The averaged values of pH in Bhimtal and Nainital, Sitatal, Ramtal and Hanumantal were statistically *at par,* respectively.

The pH values averaged over lakes showed that the pH in both years was similar. The interaction between years and lakes was also statistically non-significant.

4.3.3 Electrical conductivity (1:2)

The electrical conductivity values of the sediment (1:2, sediment:water ratio) presented in Table 4.29 showed that Nainital had the highest value (0.229 $mscm^{-1}$) followed by Bhimtal (0.189 $mscm^{-1}$), Hanumantal (0.148 $mscm^{-1}$), Sitatal (0.143 $mscm^{-1}$), Ramtal (0.139 $mscm^{-1}$), Naukuchiatal (0.122 $mscm^{-1}$) and Punatal (0.093 $mscm^{-1}$). The averaged values of electrical conductivity in all lakes were significantly different from each other.

The difference between the years and interaction between years and lakes were statistically non-significant.

4.3.4 Readily oxidisable carbon (%)

The data on year-wise variation in readily oxidisable carbon in sediments of different lakes are presented in Table 4.29.

Yearly averaged values of readily oxidizable C for different lakes indicated that the highest readily oxidizable carbon was found in Naukuchiatal (1.027) followed by Nainital (0.68 %), Bhimtal (0.54 %), Punatal and Hanumantal (0.22 %) and Sitatal and Ramtal (0.20 %). The averaged values of readily oxidizable carbon in Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par.*

The readily oxidizable C values averaged over lakes indicated that the percent of readily oxidizable carbon in year 2005 was significantly higher than the value recorded that in year 2004.

The interaction between years and lakes was statistically non-significant. However, during 2005 Naukuchiatal contained the maximum value of readily oxidisable carbon (1.06 %).

4.3.5 Total carbon (%)

The data on total carbon percentage in sediments of different lakes during 2004 and 2005 are presented in Table 4.29.

Yearly averaged values for different lakes indicated that the highest total carbon percentage was found in Naukuchiatal (2.37 %) followed by Bhimtal (1.11 %), Nainital (1.00 %), Hanumantal (0.68 %), Punatal (0.63 %), Sitatal (0.60 %) and Ramtal (0.55 %). The averaged values of total carbon percentage in Bhimtal and Nainital, Punatal, Sitatal and Ramtal and Punatal, Sitatal and Hanumantal were statistically *at par*, respectively.

The difference between the years and the interaction effect were statistically not significant.

4.3.6 $CaCo_3$ equivalent (%)

The data on $CaCO_3$ equivalent per cent in the sediments of different lakes during year 2004 and 2005 are presented in Table 4.29.

The values averaged over years for different lakes indicated that the highest $CaCO_3$ equivalent was found in Nainital (37.55 %) followed by Bhimtal (14.89 %), Ramtal (11.56 %), Hanumantal (9.90 %), Sitatal (9.83), Punatal (4.25 %) and Naukuchiatal (2.65 %). The averaged values of $CaCO_3$ equivalent in Sitatal and Hanumantal were statistically *at par.*

The effects of years and interaction between years and lakes had not significant effect on $CaCO_3$ equivalent percent.

The pH of the sediments of these lakes was alkaline. Relatively higher pH in sediments of Bhimtal and Naukuchiatal might be due to high $CaCO_3$ content and low contents of readily oxidisable carbon and total carbon.

Highest content of readily oxidisable carbon and total carbon Naukuchiatal could be attributed to a lotus pond attached to main water body and also to leaf fall from the surrounding dense vegetation. Higher content of readily oxidisable carbon and total carbon in Bhimtal and Nainital could be partly attributed to a big flock of ducks inhabiting these lakes and increased anthropogenic interferences due to large tourist in flow to these recreation spots. The carbonate content of lake sediments indicated the dominance of carbonate minerals in the catchment area from where eroded material and runoff brings mineral

Table 4.29. **The pH, electrical conductivity (EC), readily oxidisable carbon (ROC), total carbon (TC) and $CaCO_3$ equivalent of the sediments from different lakes**

Year / Lake	pH			EC (mS cm^{-1})			ROC (%)			TC (%)			$CaCO_3$ equivalent (%)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	8.92	8.71	8.81	0.192	0.187	0.189	0.53	0.56	0.54	1.10	1.12	1.11	14.81	14.97	14.89
Naukuchiatal	7.81	7.88	7.85	0.121	0.122	0.122	0.97	1.06	1.02	2.36	2.38	2.37	2.64	2.67	2.65
Punatal	7.94	8.02	7.98	0.093	0.094	0.094	0.19	0.24	0.22	0.62	0.63	0.63	4.23	4.27	4.25
Sitatal	8.05	8.13	8.09	0.143	0.144	0.144	0.19	0.21	0.20	0.59	0.60	0.60	9.78	9.88	9.83
Ramtal	8.07	8.15	8.11	0.138	0.139	0.139	0.18	0.23	0.20	0.55	0.55	0.55	11.50	11.61	11.56
Hanumantal	8.06	8.14	8.10	0.147	0.148	0.148	0.21	0.24	0.22	0.68	0.69	0.68	9.85	9.95	9.90
Nainital	8.99	8.78	8.89	0.232	0.227	0.229	0.65	0.72	0.68	0.99	1.00	1.00	37.37	37.74	37.55
Mean	8.26	8.26		0.152	0.152		0.42	0.47		0.98	0.99		12.88	13.01	
Effect	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L
CD (p=0.05)	ns	0.15	ns	ns	0.003	ns	0.02	0.04	ns	ns	0.13	ns	ns	0.72	ns

solids and a possible generation of carbonates in aquatic environment rich in alkaline earth metals.

4.4 Different chemical fractions of some metals in sediments of different lakes during 2004 and 2005

4.4.1 Chromium

The data on concentration of different chemical fractions of chromium (Cr) in sediments of different lakes during 2004 and 2005 are presented in table 4.30 & fig. 4.9.

4.4.1.1 Water soluble and exchangeable (Cr-F_1) fraction

In general, the values averaged over years revealed that Cr-F_1 fraction was the highest in Nainital (0.78 μg g^{-1}) followed by Naukuchiatal (0.75 μg g^{-1}), Bhimtal (0.74 μg g^{-1}), Punatal (0.68 μg g^{-1}) and Sitatal, Ramtal and Hanumantal (0.28 μg g^{-1}). The averaged values of Cr-F_1 fraction in Bhimtal and Naukuchiatal were statistically *at par.*

The content of Cr-F_1 fraction averaged over lakes revealed that the content in 2005 (0.55 μg g^{-1}) was significantly higher than content in 2004 (0.53 μg g^{-1}).

The interaction effect of years and lakes was statistically non-significant.

4.4.1.2 NaOAc extractable (Cr-F_2) Fraction

The values averaged over years for Cr-F_2 fraction revealed that this fraction was the highest in Nainital (1.01 μg g^{-1}) followed by Bhimtal (0.74 μg g^{-1}), Punatal and Sitatal (0.56μg g^{-1}), Naukuchiatal (0.51μg g^{-1}), Hanumantal (0.47 μg g^{-1}) and Ramtal (0.46 μg g^{-1}). The

Table 4.30. Different fraction of Cr (μg g^{-1}) in the sediment from different lakes

Lake / Year	W. S. +Exch. (F_1)			NaOAc extractable (F_2)			Organically bound (F_3)			Reducible (F_4)			Residual (F_5)			Total (F_t)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	0.72	0.77	0.74	0.72	0.77	0.74	0.64	0.76	0.70	2.05	2.69	2.37	13.6	14.1	13.9	17.7	19.1	18.4
Naukuchiatal	0.73	0.78	0.75	0.50	0.53	0.51	0.66	0.84	0.75	1.21	1.26	1.23	16.3	17.0	16.7	19.4	20.4	19.9
Punatal	0.67	0.70	0.68	0.54	0.59	0.56	0.36	0.32	0.34	1.20	1.59	1.40	15.4	16.7	16.0	18.2	19.9	19.1
Sitatal	0.27	0.30	0.28	0.54	0.58	0.56	0.34	0.31	0.33	0.88	1.25	1.06	13.8	14.4	14.1	16.2	16.9	16.5
Ramtal	0.27	0.30	0.28	0.44	0.48	0.46	0.33	0.31	0.32	0.83	0.89	0.86	12.4	13.4	12.9	14.3	15.4	14.8
Hanumantal	0.27	0.30	0.28	0.45	0.49	0.47	0.34	0.32	0.33	0.94	0.98	0.96	12.5	13.2	12.9	14.5	15.3	14.9
Nainital	0.78	0.80	0.79	0.97	1.06	1.01	0.64	0.66	0.65	1.25	1.63	1.44	16.7	17.4	17.1	20.4	21.5	21.0
Mean	0.53	0.56		0.59	0.64		0.47	0.50		1.19	1.47		14.4	15.2		17.2	18.4	
Effect	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L
CD (p=0.05)	0.02	0.03	ns	0.01	0.02	ns	0.02	0.03	0.04	0.10	0.18	0.25	0.5	0.9	ns	0.5	0.9	ns

average values of $Cr\text{-}F_2$ fraction in Ramtal and Hanumantal were statistically *at par.*

The value averaged over lakes indicated that the accumulation of $Cr\text{-}F_2$ fraction in 2005 (0.64) was significantly higher than that of 2004 (0.59 μg g^{-1}).

The interaction between years and lakes was statistically non-significant.

4.4.1.3 Organically bound (oxidisable) $Cr\text{-}F_3$ fraction

The yearly averaged value of $Cr\text{-}F_3$ fraction was highest in Naukuchiatal (0.75 μg g^{-1}) followed by Bhimtal (0.70 μg g^{-1}), Nainital (0.65 μg g^{-1}), Punatal (0.75 μg g^{-1}), Sitatal and Hanumantal (0.33 μg g^{-1}) and Ramtal (0.32 μg g^{-1}). The averaged values of $Cr\text{-}F_3$ fraction in Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par.*

The mean content of $Cr\text{-}F_3$ fraction was higher in 2005 (0.50 μg g^{-1}) as compared to 2004 (0.47 μg g^{-1}).

The interaction effect between years and lakes was also statistically significant. The values of $Cr\text{-}F_3$ fraction in Sitatal, Ramtal, Hanumantal and Nainital during both the years were statistically *at par.* While, the values of $Cr\text{-}F_3$ fraction in Bhimtal and Naukuchiatal in year 2005 were significantly higher than those observed in 2004. However, the reverse was the case for Punatal.

4.4.1.4 Iron and Mn oxide bound (reducible) $Cr\text{-}F_4$ fraction

The yearly averaged value of $Cr\text{-}F_4$ fraction in sediments of different lakes indicated that the highest content of $Cr\text{-}F_4$ fraction was found in Bhimtal (2.37 μg g^{-1}) followed by Nainital (1.44 μg g^{-1}), Punatal

(1.40 μg g^{-1}), Naukuchiatal (1.23 μg g^{-1}), Sitatal (1.06 μg g^{-1}), Hanumantal (0.96 μg g^{-1}) and Ramtal (0.86 μg g^{-1}), The averaged values of Cr-F_4 fraction in Naukuchiatal and Punatal, Punatal and Nainital, Sitatal and Hanumantal and Ramtal and Hanumantal were statistically *at par* with each other, respectively.

The values averaged over lakes indicated that the Cr-F_4 fraction in 2005 (1.47 μg g^{-1}) was significantly higher than that in 2004 (1.19 μg g^{-1}).

The interaction between years and lakes was significant. The highest Cr-F_4 fraction was found in Bhimtal during 2005 (2.69 while the lowest was noted in Ramtal during 2004 (0.83 μg g^{-1}). The values recorded during 2004 and 2005 for Naukuchiatal, Ramtal and Hanumantal were statistically *at par*.

4.4.1.5 Residual (Cr-F_5) fraction

The values of Cr-F_5 fraction averaged over years in sediments of different lakes varied from 12.9 to 17.1 μg g^{-1}. The highest content of this fraction was found in Nainital (17.1μg g^{-1}) and the lowest was noted in Ramtal (12.9 μg g^{-1}) and Hanumantal. Bhimtal, Naukuchiatal, Punatal and Sitatal contained 13.9, 16.7, 16.0 and 14.1 μg Cr-F_5 fraction g^{-1}, respectively. The averaged values of Cr-F_5 in Naukuchiatal and Punatal were statistically *at par* with each other.

The values of Cr-F_5 fraction averaged over lakes in 2005 were significantly higher than that in 2004. The interaction between years and lakes was statistically non-significant.

4.4.1.6 Total Cr

Yearly averaged values of total concentration of Cr in sediments of different lakes indicated that the highest total Cr content was found in Nainital (21.0 μg g^{-1}) followed by Naukuchiatal (19.9 μg g^{-1}), Punatal (19.1 μg g^{-1}), Bhimtal (18.4 μg g^{-1}), Sitatal (16.5 μg g^{-1}), Hanumantal (14.9 μg g^{-1}) and Ramtal (14.8 μg g^{-1}). The averaged values of total Cr fraction in Bhimtal and Punatal, Naukuchiatal and Punatal, and Ramtal and Hanumantal were statistically *at par*, respectively.

As regards the effect of year, the mean value of total Cr in 2005 (18.4 μg g^{-1}) was significantly higher than in 2004 (17.2 μg g^{-1}).

The interaction between years and lakes had significant effect on this fraction. However, the maximum content of total Cr was noted in Nainital during 2005 (21.5 μg g^{-1}) while the minimum was recorded in Ramtal during 2004 (14.3 μg g^{-1}).

It is apparent from the data that the residual (Cr-F_5) fraction was the most dominant fraction of Cr in the sediments of all lakes (Appendix-I). Lindau and Hossner (1982) also noted that about 87 % of total Cr associated with alkaline and silicate minerals. Iron and Mn-oxide bound (Cr-F_4) fraction represented the second most dominant fraction in lake sediments. A close association of Cr content with Fe-oxide has been reported by Zachara *et al.* (1989). On an average, carbonate bound (Cr-F_2) fraction was the third dominant fraction of Cr in lake sediments. Interestingly, the highest content of this fraction was

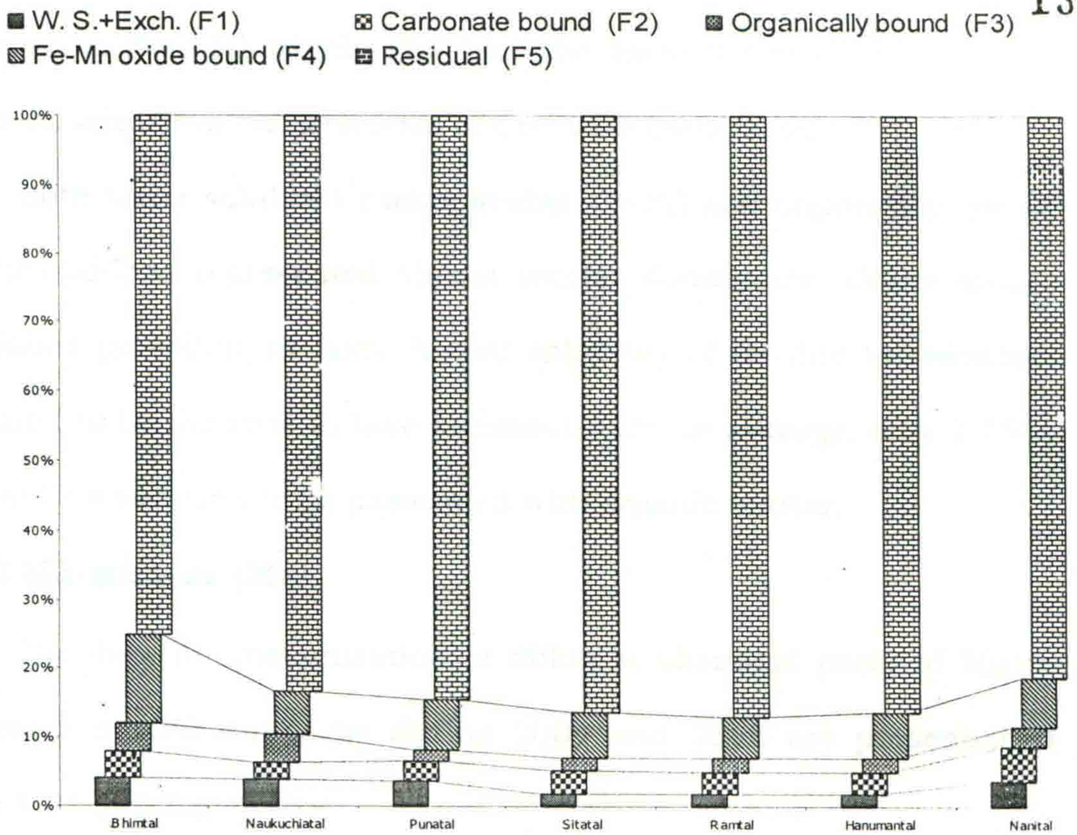

Fig. 4.9 Chemical fractions of Cr as percentage of total metal content in sediments

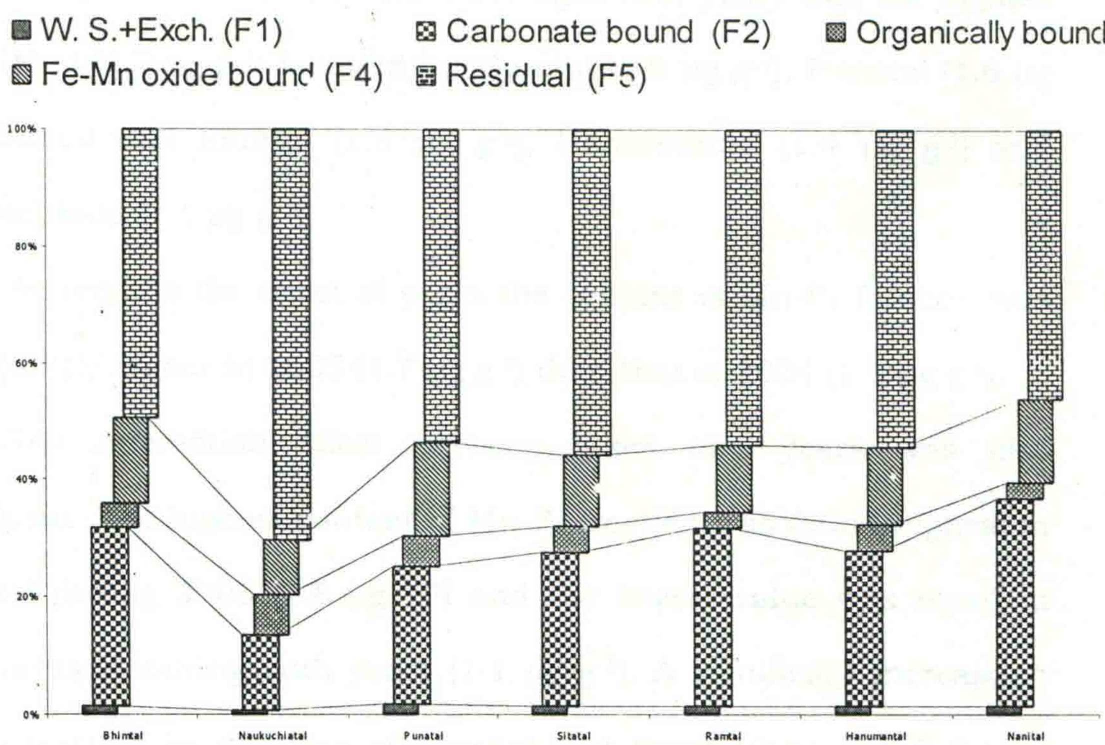

Fig. 4.10 Chemical fractions of Mn as percentage of total metal content in sediments

recorded in Nainital which also had the highest $CaCO_3$ % and this indicated affinity of reduced form of Cr^{3+} with carbonates.

Both water soluble + exchangeable ($Cr-F_1$) and organically bound ($Cr-F_3$) fractions represented almost similar dominance. Under anoxic conditions prevailing in lakes higher solubility of Cr due to reduction appeared to be the case in lake sediments. On an average, only 2.75 % of total Cr was found to be associated with organic matter.

4.4.2 Manganese (Mn)

The data on concentration of different chemical pools of Mn in sediments of different lakes during 2004 and 2005 are presented in Table 4.31 and Fig. 4.10.

4.4.2.1 Water soluble and exchangeable ($Mn-F_1$) fraction

The value of $Mn-F_1$ fraction averaged over years was the highest in Nainital (2.7 µg g^{-1}) followed by Bhimtal (1.8 µg g^{-1}), Punatal (1.6 µg g^{-1}), Sitatal and Ramtal (1.5 µg g^{-1}), Hanumantal (1.4 µg g^{-1}) and Naukuchiatal (1.1 µg g^{-1}).

As regards the effect of years the content of $Mn-F_1$ fraction was significantly higher in 2005 (1.7 µg g^{-1}) than that of 2004 (1.6 µg g^{-1}).

The interaction effect between lakes and years was also significant. The highest content of $Mn-F_1$ fraction was found highest in Nainital during 2005 (2.8 µg g^{-1}) and the lowest value was noted in Naukuchiatal during both years (1.1 µg g^{-1}). A significant increase in $Mn-F_1$ fraction in the case of Nainital and Ramtal was noted during 2005 as compared to 2004.

Table 4.31. Different fraction of Mn ($\mu g\ g^{-1}$) in the sediment from different lakes

Lake / Year	W. S. +Exch. (F_1)			NaOAc extractable (F_2)			Organically bound (F_3)			Reducible (F_4)			Residual (F_5)			Total (E_t)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	1.7	1.8	1.8	36.2	36.2	36.2	4.9	5.2	5.1	16.7	17.7	17.2	56.3	62.0	59.2	102.2	123.0	112.6
Naukuchiatal	1.1	1.1	1.1	20.4	21.4	20.9	10.5	11.1	10.8	14.7	16.0	15.3	111.9	115.3	113.6	174.9	164.9	169.9
Punatal	1.6	1.6	1.6	22.2	23.2	22.7	3.8	4.8	4.3	15.3	15.6	15.5	50.8	52.1	51.4	93.6	97.3	95.4
Sitatal	1.4	1.5	1.5	24.3	25.6	25.0	3.1	4.2	3.6	11.5	11.5	11.5	52.4	53.7	53.1	94.4	96.5	95.4
Ramtal	1.2	1.7	1.5	30.5	31.8	31.2	2.1	2.9	2.5	11.7	11.4	11.5	54.5	55.8	55.2	90.1	103.3	96.7
Hanumantal	1.4	1.4	1.4	24.5	25.5	25.0	3.6	4.4	4.0	11.9	12.9	12.4	50.5	51.5	51.0	97.6	96.0	96.8
Nainital	2.6	2.8	2.7	61.4	73.1	67.3	4.9	5.3	5.1	25.4	28.7	27.1	86.3	87.6	86.9	180.7	197.5	189.1
Mean	1.6	1.7		31.4	33.8		4.7	5.4		15.3	16.3		66.1	68.3		119.0	125.5	
Effect	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L
CD (p=0.05)	0.1	0.1	0.2	ns	6.8	ns	0.1	0.2	0.3	0.5	0.9	1.3	1.6	3.1	ns	1.8	3.3	4.7

4.4.2.2 NaOAc extractable (Mn-F_2) fraction

On the yearly mean value basis, the highest Mn-F_2 fraction was recorded in Nainital (67.3 µg g^{-1}) followed by Bhimtal (36.2 µg g^{-1}), Ramtal (81.2 µg g^{-1}), Sitatal and Hanumantal (25.0 µg g^{-1}), Punatal (22.7 µg g^{-1}) and Naukuchiatal (20.9 µg g^{-1}). The averaged values of Mn-F_2 Bhimtal and Ramtal, Naukuchiatal, Punatal, Sitatal and Hanumantal, Punatal, Sitatal and Hanumantal and Sitatal, Ramtal and Hanumantal were statistically *at par,* respectively.

The effect of interaction between years and lakes was statistically non- significant.

4.4.2.3 Organic bound (oxidisable) (Mn-F_3) fraction

Yearly averaged values of Mn-F_3 fraction indicated that the highest content of Mn-F_3 fraction was noted in Naukuchiatal (10.88 µg g^{-1}) followed by Bhimtal and Nainital (5.1 µg g^{-1}), Punatal (4.3 µg g^{-1}), Hanumantal (4.0 µg g^{-1}), Sitatal (3.6 µg g^{-1}) and Ramtal (2.5 µg g^{-1}).

As regards the effect of years, Mn-F_3 fraction was found significantly higher in 2005 (5.4 µg g^{-1}) as compared to 2004 (4.7 µg g^{-1}).

As regards the interaction effect of years and lakes, Naukuchiatal during 2005 contained the highest concentration of Mn-F_3 while the lowest content was noted in Ramtal during 2004. As compared to the year 2004, a significant increase in Mn-F_3 was noted in all lakes during 2005.

4.4.2.4 Iron and Mn-oxide bound (reducible) (Mn-F_4) fraction

The values of Mn-F_4 fraction averaged over years indicated that the highest Mn-F_4 fraction was in Nainital (27.1 μg g^{-1}), followed by Bhimtal (17.2 μg g^{-1}), Punatal (15.5 μg g^{-1}), Naukuchiatal (15.3 μg g^{-1}), Hanumantal (12.4 μg g^{-1}) and Sitatal and Ramtal (11.5 μg g^{-1}). The averaged values of Mn-F_4 in Naukuchiatal and Punatal were statistically *at par.*

As regards the effect of years, the Mn-F_4 fraction observed during 2005 (16.3 μg g^{-1}) was significantly higher than the value recorded during 2004 (15.3 μg g^{-1}).

The effect of interaction between years and lakes was statistically significant. The highest content of Mn-F_4 was noted in Nainital during 2005 (28.7 μg g^{-1}) and the lowest was noted in Ramtal during 2004 (11.4 μg g^{-1}). The averaged values of Mn-F_4 fraction in Bhimtal, Sitatal, Hanumantal and Nainital during both years were statistically *at par.*

4.4.2.5 Residual Mn-F_5 fraction

The values of Mn-F_5 fraction in sediments of different lakes averaged over years indicated that the highest value of Mn-F_5 fraction was recorded in Naukuchiatal (113.6 μg g^{-1}) followed by Nainital (86.9 μg g^{-1}), Bhimtal (59.2 μg g^{-1}), Ramtal (55.2 μg g^{-1}), Sitatal (53.1 μg g^{-1}), Punatal (51.4 μg g^{-1}) and Hanumantal (51.0 μg g^{-1}). The averaged values of Mn-F_5 fraction in Punatal, Sitatal and Hanumantal and, Sitatal and Ramtal were statistically *at par,* respectively.

On the yearly mean basis, Mn-F_5 fraction in 2005 (68.3 μg g^{-1}) was significantly higher than that in 2004 year (66.1 μg g^{-1}). The interaction effect between years and lakes was statistically non-significant.

4.4.2.6 Total Mn

The data on total Mn concentration in sediments of different lakes indicated that the highest concentration of total Mn was found in Nainital (189.1 $\mu g\ g^{-1}$) followed by Naukuchiatal (169.9 $\mu g\ g^{-1}$), Bhimtal (112.6 $\mu g\ g^{-1}$), Hanumantal (96.8 $\mu g\ g^{-1}$), Ramtal (96.7 $\mu g\ g^{-1}$) and Punatal and Sitatal (95.4 $\mu g\ g^{-1}$). The averaged values of total Mn in Punatal, Sitatal and Ramtal were statistically *at par.*

On the yearly mean basis, total Mn in 2005 (125.5 $\mu g\ g^{-1}$) was significantly higher than that in 2004 (119.0 $\mu g\ g^{-1}$).

As regards the interaction effect between years and lakes, the highest values of total Mn was noted in Nainital during 2005 (197.5 $\mu g\ g^{-1}$) while the lowest value was noted in Ramtal during 2004 (90.1 $\mu g\ g^{-1}$). Total Mn during 2005 was found to be significantly higher in Bhimtal, Punatal, Ramtal and Nainital as compared to contents during 2004. In the case of Naukuchiatal, total content of Mn during 2004 was significantly higher than that in 2005.

Like Cr, residual (Mn-F_5) fraction represented the most dominant fraction of Mn in lake sediments. This was expected as the lakes received most of Mn supply through suspended particulates coming alongwith runoff. Lindau and Hossner (1982) also noted that in natural marshes 53 % of Mn locked in residual fraction. Manganese-F_2 fraction represented the second most dominant fraction of Mn in lake sediments. The highest content of Mn-F_2 was recorded in Nainital which also had the highest CaCO3 content in sediments. Manganese is one of the micronutrient cation which has been reported to get fixed on the surface of $CaCO_3$ particulate (Lindau and Hossner, 1982).

Iron and Mn-oxide (Mn-F_4) fraction represented the third most dominant fraction of Mn in lake sediments. Lindau and Hossner (1982) also noted that 11 % of Mn in natural marshes existed as easily reducible fraction and attributed it to gradual transformation of $Mn(OH)_2$ associated with suspended matter into residual phase. The next dominant fraction of Mn in lake sediment was that of organically bound (Mn-F_3) fraction. Mn is known to be complexed by water soluble and insoluble fractions of organic matter. The insoluble fraction especially under alkaline pH condition binds Mn irreversibly while water soluble fraction is known to enhance the solubility of Mn (Page, 1962). Water soluble + exchangeable (Mn-F_1) fraction represented the smallest fraction of Mn in lake sediments and it was anticipated due to alkaline pH of lake sediment. Lindsay (1972) showed that soluble Mn content decreased 100 fold for each unit increase in pH.

4.4.3 Iron (Fe)

The data on concentration of different chemical pools of Fe in sediments of different lakes during 2004 and 2005 are presented in Table 4.32 & Fig. 4.11.

4.4.3.1 Water soluble and exchangeable (Fe-F_1) fraction

The values of Fe-F_1 fraction averaged over years indicated that this fraction was the highest in Nainital (3.2 μg g^{-1}) followed by Bhimtal (2.5 μg g^{-1}), Naukuchiatal, Sitatal, Ramtal and Hanumantal (1.7 μg g^{-1})

Table 4.32. Different fraction of Fe (μg g^{-1}) in the sediment from different lakes

Lake / Year	W. S. +Exch. (F_1)			NaOAc extractable (F_2)			Organically bound (F_3)			Reducible (F_4)			Residual (F_5)			Total (F_t)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	2.3	2.7	2.5	26.3	25.0	25.7	34.3	36.6	35.4	582.4	588.7	585.6	4855	4832	4844	5501	5485	5493
Naukuchiatal	1.6	1.7	1.7	6.5	6.7	6.6	55.5	57.9	56.7	352.6	358.2	355.4	5937	6003	5970	6353	6428	6391
Punatal	1.7	1.6	1.6	9.3	9.6	9.4	30.1	32.4	31.3	391.7	394.7	393.2	4859	5125	4992	5292	5564	5428
Sitatal	1.7	1.7	1.7	16.1	16.6	16.3	25.2	26.5	25.8	400.1	403.8	401.9	4861	5061	4961	5304	5510	5407
Ramtal	1.7	1.6	1.7	17.9	18.0	18.0	21.3	22.6	21.9	356.5	363.2	359.9	5024	5190	5107	5421	5596	5508
Hanumantal	1.6	1.7	1.7	17.4	17.7	17.5	27.0	28.0	27.5	318.9	328.9	323.9	4938	5138	5038	5303	5514	5409
Nainital	3.2	3.2	3.2	122.6	125.6	124.1	34.3	35.3	34.8	403.8	403.8	403.8	4701	4801	4751	5265	5369	5317
Mean	2.0	2.0		30.9	31.3		32.5	34.2		400.9	405.9		5025	5165		5491	5638	
Effect	Year (Y)	Lake (L)	Yx L	Year (Y)	Lake (L)	YxL	Year (Y)	Lake (L)	YxL	Year (Y)	Lake (L)	YxL	Year (Y)	Lake (L)	YxL	Year (Y)	Lake (L)	YxL
CD (p=0.05)	ns	0.2	ns	ns	1.4	ns	1.3	2.4	ns	4.1	7.6	ns	68	127	ns	68	126	ns

and Punatal (1.6 μg g^{-1}). The averaged values of Fe-F_1 Fraction in Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par.*

As regards the effect of years and interaction of years X lakes, the variations were statistically non- significant.

4.4.3.2 NaOAc extractable (Fe-F_2) fraction

The values of Fe-F_2 fraction averaged over years indicated that this fraction was the highest in Nainital (124.1 μg g^{-1}) followed by Bhimtal (25.7 μg g^{-1}), Ramtal (18.0 μg g^{-1}), Hanumantal (17.5 μg g^{-1}), Sitatal (16.3 μg g^{-1}), Punatal (9.4 μg g^{-1}) and Naukuchiatal (6.6 μg g^{-1}). The averaged values of Fe-F_2 fraction in Sitatal and Hanumantal and Ramtal and Hanumantal were statistically *at par*, respectively.

The effect of years and interaction of years X lakes had no significant influence on the contents of Fe-F_2 fraction.

4.4.3.3 Organically bound (Fe-F_3) fraction

On the mean value basis, the highest concentration of Fe-F_3 fraction was found in Naukuchiatal (56.7 μg g^{-1}) followed by Bhimtal (35.4 μg g^{-1}), Nainital (34.8 μg g^{-1}), Punatal (31.3 μg g^{-1}), Hanumantal (27.5 μg g^{-1}), Sitatal (25.8 μg g^{-1}), and Ramtal (21.9 μg g^{-1}). The averaged values of Fe-F_3 Fraction in Bhimtal and Nainital and, Sitatal and Hanumantal were statistically *at par,* respectively.

The values averaged over lakes showed that the concentration of Fe-F_3 during 2005 (34.2 μg g^{-1}) was significantly higher than the value in 2004 (32.5 μg g^{-1}).

The effect of interaction between years and lakes was statistically non- significant.

4.4.3.4 Iron and Mn oxide bound (reducible) ($Fe-F_4$) fraction

The yearly averaged values of $Fe-F_4$ fraction in sediments of different lakes indicated that the highest content of $Fe-F_4$ fraction was found in Bhimtal (586.4 μg g^{-1}) followed by Nainital (403.8 μg g^{-1}), Sitatal (401.9 μg g^{-1}), Punatal (393.2 μg g^{-1}), Ramtal (359.8 μg g^{-1}), Naukuchiatal (355.4 μg g^{-1}) and Hanumantal (323.9 μg g^{-1}). The averaged values of $Fe-F_4$ fraction in Naukuchiatal and Ramtal and, Sitatal and Nainital were statistically *at par,* respectively.

On the mean value basis, the $Fe-F_4$ fraction during 2005 (405.9 μg g^{-1}) was significantly higher than the value in 2004 (400.9 μg g^{-1}).

The effect of interaction between years and lakes was statistically non- significant.

4.4.3.5 Residual ($Fe-F_5$) fraction

The values averaged over years showed that the highest content of $Fe-F_5$ fraction was found in Naukuchiatal (5970μg g^{-1}) followed by Ramtal (5107 μg g^{-1}), Hanumantal (5038 μg g^{-1}), Punatal (4992 μg g^{-1}), Sitatal (4961 μg g^{-1}), Bhimtal (4844 μg g^{-1}) and Nainital (4751 μg g^{-1}). The averaged values of $Fe-F_5$ fraction in Bhimtal and Nainital, Bhimtal and Sitatal, Punatal, Sitatal and Hanumantal and Punatal, Ramtal and Hanumantal were statistically *at par,* respectively.

On the mean value basis, the $Fe-F_5$ fraction during 2005 (5165 μg g^{-1}) was significantly higher than the value in 2004 (5025 μg g^{-1}).

The effect of interaction between years and lakes was statistically non-significant.

4.4.3.6 Total Fe

The values of total iron content averaged over years indicated that was the highest total iron content was found in Naukuchiatal (6391 μg g^{-1}) followed by Ramtal (5508 μg g^{-1}), Bhimtal (5493 μg g^{-1}), Punatal (5428 μg g^{-1}) Hanumantal (5409 μg g^{-1}), Sitatal (5407 μg g^{-1}) and Nainital (5317 μg g^{-1}). The averaged values of total Fe in Bhimtal, Punatal, Sitatal, Ramtal and Hanumantal and, Punatal, Sitatal, Hanumantal and Nainital were statistically *at par* with each other, respectively.

On the basis of mean value, the total iron content during 2005 (5638 μg g^{-1}) was significantly higher than the value in 2004 (5491 μg g^{-1}).

The effect of interaction between years and lakes was statistically non- significant.

As the. regards the distribution of Fe in different chemical fractions in lake sediments, residual (Fe-F_5) fraction was the most dominant fraction as it represented 88.18 to 93.42 % of total iron, Chester and Hughes (1969) also noted that about 85 % of the sediment iron was fixed in residual phase of deep sea sediment. Iron associated to reducible fraction (Fe-F_4) represented the second most fraction accounting to only 5.56 to 10.66 % of total Fe in lake sediment. Lindau and Hossner (1982) also noted similar behaviour and attributed the

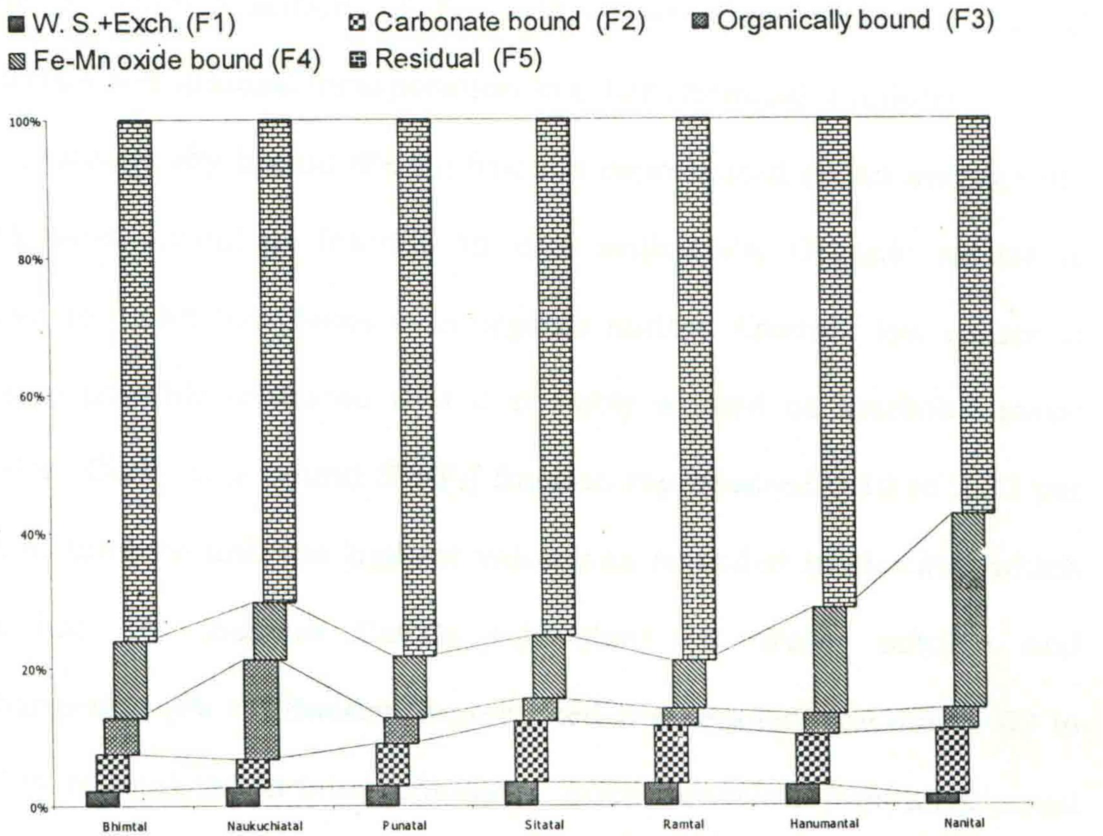

Fig. 4.11 Chemical fractions of Fe as percentage of total metal content in sediments

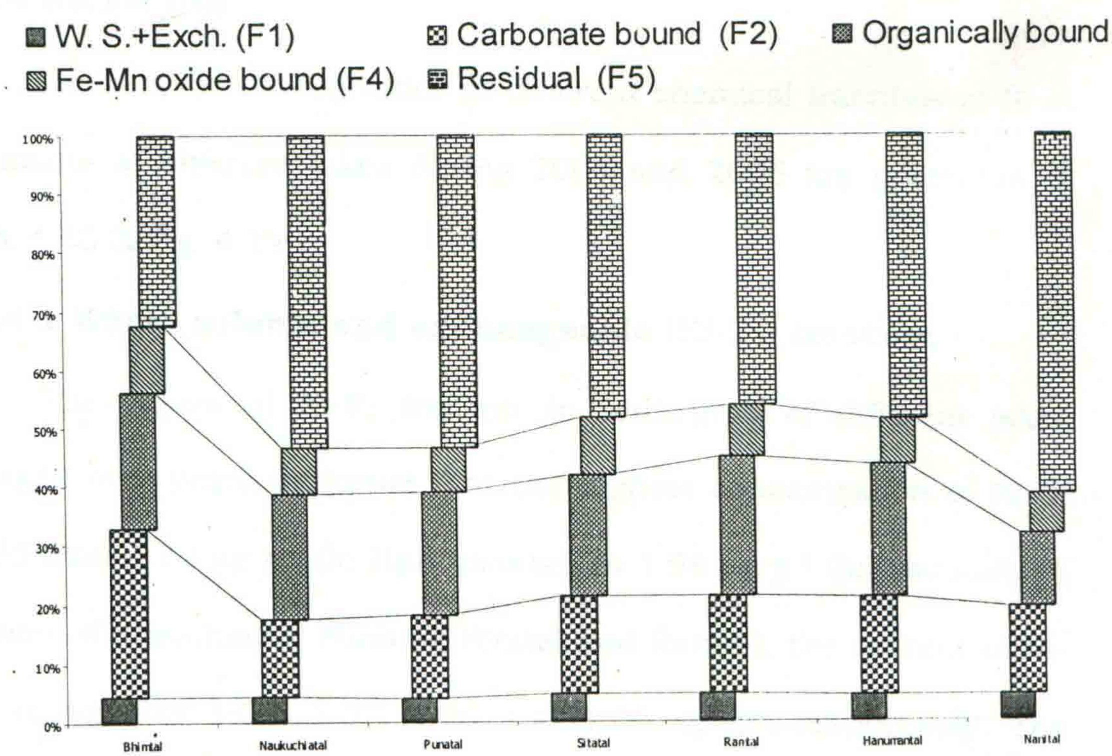

Fig. 4.12 Chemical fractions of Ni as percentage of total metal content in sediments

same to transformation of Fe oxides associated with suspended materials and gradual incorporation in other chemical fractions.

Organically bound (Fe-F_3) fraction represented on an average the third most abundant fraction in lake sediments. Organic matter is known to make complexes with organic matter. Overall, low values of fraction possibly indicated that it possibly existed as insoluble static fraction. Carbonate bound (Fe-F_2) fraction represented 0.10 to 2.33 per cent of total Fe and the highest value was recorded in Nainital which also had the highest $CaCO_3$ equivalent %. Water soluble and exchangeable (Fe-F_1) fraction represented the smallest fraction (0.03 to 0.06 % of total Fe) in lake sediments. Such behaviour was anticipated in view of alkaline pH of lake sediment. Lindsay (1984) also reported the minimum solubility of Fe in pH of 7.4 to 8.5.

4.4.4 Nickel (Ni)

The data on concentration of different chemical fractions of Ni in sediments of different lakes during 2004 and 2005 are presented in Table 4.33 & Fig. 4.12.

4.4.4.1 Water soluble and exchangeable (Ni-F_1) fraction

The values of Ni-F_1 fraction in sediments of different lakes averaged over years indicated that the highest concentration of Ni-F_1 varied from 1.02 $\mu g\ g^{-1}$ (in Hanumantal) to 1.98 $\mu g\ g^{-1}$ (in Nainital). In Bhimtal, Naukuchiatal, Punatal, Sitatal and Ramtal, the content of Ni-F_1 fraction was 1.04, 1.07, 1.06 and 1.06 $\mu g\ g^{-1}$, respectively. The

Table 4.33. Different fraction of Ni ($\mu g\ g^{-1}$) in the sediment from different lakes

Lake / Year	W. S. +Exch. (F_1)			NaOAc extractable (F_2)			Organically bound (F_3)			Reducible (F_4)			Residual (F_5)			Total (F_t)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	1.04	1.04	1.04	6.70	6.42	6.56	3.57	5.37	4.47	2.59	2.50	2.54	6.6	8.4	7.5	20.5	23.7	22.1
Naukuchiatal	1.05	1.08	1.07	3.36	3.20	3.28	2.64	5.27	3.96	1.41	2.44	1.93	13.2	13.5	13.3	21.6	25.5	23.5
Punatal	1.01	1.06	1.04	3.57	3.35	3.46	2.10	5.15	3.62	1.60	2.10	1.85	13.3	13.0	13.1	21.6	24.6	23.1
Sitatal	1.06	1.05	1.06	3.55	3.41	3.48	2.04	4.43	3.23	2.17	2.07	2.12	10.1	10.6	10.3	18.9	21.5	20.2
Ramtal	1.03	1.08	1.06	3.71	3.38	3.54	2.02	5.17	3.59	1.56	2.40	1.98	9.4	10.7	10.0	17.7	22.7	20.2
Hanumantal	1.02	1.02	1.02	3.78	3.60	3.69	2.01	5.06	3.53	1.35	2.16	1.76	10.1	11.8	11.0	18.3	23.7	21.0
Nainital	1.97	1.98	1.98	6.01	6.80	6.40	2.44	5.27	3.86	2.27	3.86	3.07	25.6	28.0	26.8	38.3	45.9	42.1
Mean	1.17	1.19		4.38	4.31		2.40	5.10		1.85	2.50		12.6	13.7		22.4	26.8	
Effect	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L
CD (p=0.05)	ns	0.06	ns	ns	0.31	0.44	0.09	0.17	0.24	0.11	0.21	0.30	0.3	0.5	0.7	0.4	0.7	1.0

averaged values in Bhimtal, Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par.*

As regards the effect of years and interaction between years and lakes, the variations were found to be statistically non- significant.

4.4.4.2 NaOAc extractable (Ni-F_2) fraction

The values of Ni-F_2 fraction averaged over years indicated that the highest concentration was found in Bhimtal (6.56 μg g^{-1}) followed by Nainital (640 μg g^{-1}), Hanumantal (3.69 μg g^{-1}), Ramtal (3.54 μg g^{-1}), Sitatal (3.48 μg g^{-1}), Punatal (3.46 μg g^{-1}) and Naukuchiatal (3.28 μg g^{-1}). The averaged values of Ni-F_2 Fraction in Bhimtal and Nainital; Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par,* respectively.

As regards the effect of years and interaction between years and lakes, the variations were found to be statistically non- significant.

4.4.4.3 Organically bound (oxidisable) (Ni-F_3) fraction

On the basis of mean value, the highest concentration of Ni-F_3 fraction was found in Bhimtal (4.47 μg g^{-1}) followed by Naukuchiatal (3.96 μg g^{-1}), Nainital (3.86 μg g^{-1}), Punatal (3.62 μg g^{-1}), Ramtal (3.59 μg g^{-1}), Hanumantal (3.53 μg g^{-1}) and Sitatal (3.23 μg g^{-1}). The averaged values of Ni-F_3 fraction in Naukuchiatal and Nainital and Punatal, Ramtal and Hanumantal were statistically *at par*, respectively.

The values averaged over lakes showed that the concentration of Ni-F_3 fraction during 2005 (5.10 μg g^{-1}) was significantly higher than the value observed in 2004 (2.40 μg g^{-1}).

The effect of interaction between years and lakes was statistically significant. The highest concentration of Ni-F_3 fraction was found in Bhimtal during 2005 (5.37 μg g^{-1}) and the lowest was noted in Hanumantal during 2004 (2.01 μg g^{-1}). As compared to 2004 a significant increase in Ni-F_3 fraction was noted for all lakes during 2005.

4.4.4.4 Iron and Mn oxide bound (reducible) (Ni-F_4) fraction

The yearly averaged values of Ni-F_4 fraction in sediments of different lakes indicated that the highest content of Ni-F_4 fraction was found in Nainital (3.07 μg g^{-1}), followed by Bhimtal (2.54 μg g^{-1}), Sitatal (2.12 μg g^{-1}),. Ramtal (1.98 μg g^{-1}), Naukuchiatal (1.93 μg g^{-1}), Hanumantal (1.76 μg g^{-1}) and Punatal (1.85 μg g^{-1}). The averaged values of Ni-F_4 Fraction in Naukuchiatal, Punatal and Ramtal; Naukuchiatal, Sitatal and Ramtal; Naukuchiatal, Punatal and Ramtal; and Naukuchiatal, Punatal and Hanumantal were statistically *at par*, respectively.

As regards the effect of year, the content of Ni-F_4 fraction in 2005 (1.85 μg g^{-1}) was significantly higher than the value in 2004 (2.5 μg g^{-1}).

The effect of interaction between years and lakes was statistically significant. The highest concentration of Ni-F_4 fraction was found in Nainital during 2005 (3.86 μg g^{-1}) and the lowest was noted in Hanumantal during 2004 (1.35 μg g^{-1}). The values obtained for Bhimtal and Sitatal during both the years were statistically *at par*.

4.4.4.5 Residual ($Ni-F_5$) fraction

The values averaged over years showed that the highest content of $Ni-F_5$ fraction was found in Nainital (26.8 μg g^{-1}) followed by Naukuchiatal (13.3μg g^{-1}), Punatal (13.1μg g^{-1}), Hanumantal (11.0 μg g^{-1}), Sitatal (10.3 μg g^{-1}), Ramtal (10.0 μg g^{-1}) and Bhimtal (7.5 μg g^{-1}). The averaged values of $Ni-F_5$ fraction in Naukuchiatal and Punatal and Sitatal and Ramtal were statistically *at par,* respectively.

On the basis of mean value, the $Ni-F_5$ fraction during 2005 (13.7 μg g^{-1}) was significantly higher than the value in 2004 (12.6 μg g^{-1}).

The effect of interaction between years and lakes was also statistically significant. The highest concentration of $Ni-F_5$ fraction was found in Nainital during 2005 (28.0 μg g^{-1}) and the lowest value was noted in Bhimtal during 2004 (6.6 μg g^{-1}). The values recorded for Naukuchiatal, Punatal and Sitatal during both the years were statistically *at par.*

4.4.4.6 Total Ni

The values of total Nickel content averaged over years indicated that was the highest total nickel content was found in Nainital (42.1 μg g^{-1}) followed by Naukuchiatal (23.5 μg g^{-1}), Punatal (23.1 μg g^{-1}), Bhimtal (22.1 μg g^{-1}), Hanumantal (21.0 μg g^{-1}) and Sitatal and Ramtal (20.2 μg g^{-1}), The averaged values of total Ni fraction in Naukuchiatal and Punatal were statistically *at par.*

As regards the effect of years, the content of total Ni in 2005 (26.8 μg g^{-1}) was significantly higher than the content observed in 2004 (22.4 μg g^{-1}).

As regards the effect of interaction between years and lakes, the highest concentration of total Ni was found in Nainital during 2005 (45.9 μg g^{-1}) while the lowest was noted in Ramtal during 2004 (17.7 μg g^{-1}).

The relative distribution of Ni in different chemical fractions in lake sediments indicated that the residual (Ni-F_5) fraction represented the most dominant fraction as it accounted for 33.98 to 63.66 % of total Ni in lake sediments. Lindau and Hossner (1982) also found that about 53 % of total Ni in sediments was fixed in the residual fraction. Next to residual fraction, the second most dominant fraction was organically bound (Ni-F_3) fraction which represented 12.52 to 25.55 % of total Ni. These findings were in concordance to those of Lindau and Hossner (1982). Carbonate bound (Ni-F_2) fraction was the third most dominant fraction of Ni (represented 13.94 to 29.64 % of total Ni). The percentage of this fraction was relatively higher in Bhimtal while Ca CO_3 equivalent % was the highest in Nainital. This possibly indicated that the nature of carbonates might have a possible role in trapping this heavy metal. Iron and manganese oxide bound (Ni-F_4) fraction accounted for 7.28 to 11.49 % total Ni. Sesquioxides especially, Mn oxides are known to retain Ni in sediment (Lindau and Hossner, 1982). Water soluble + exchangeable (Ni-F_1) fraction represented the least dominant fraction of Ni and accounted for on an average 4.81 % of total Ni.

4.4.5 Copper (Cu)

The data on concentration of different chemical fractions of Cu in sediments of different lakes during 2004 and 2005 are presented in Table 4.34 & Fig. 4.13.

4.4.5.1 Water soluble and exchangeable (Cu-F_1) fraction

The values of Cu-F_1 fraction in sediments of different lakes averaged over years indicated that the highest concentration of Cu-F_1 fraction varied from 0.32 μg g^{-1} (in Naukuchiatal) to 0.63 μg g^{-1} (in Nainital). In Bhimtal, Punatal, Sitatal and Ramtal, the content of Cu-F_1 fraction was 0.54, 0.35 0.41, 0.42 and 0.39 μg g^{-1}, respectively.

As regards the effect of years the variations were found to be statistically non- significant. The effect of interaction between years and lakes was statistically significant. The highest concentration of Cu-F_1 fraction was found in Nainital during 2004 (0.31μg g^{-1}). As compared to contents of Cu-F_1 fraction in 2004, a significant reduction in Cu-F_1 fraction was noted in Bhimtal and Nainital during 2005. While an increase in Cu-F_1 fraction was recorded in 20005 for Naukuchiatal, Sitatal, Ramtal and Hanumantal.

4.4.5.2 NaOAc extractable (Cu-F_2) fraction

The values of Cu-F_2 fraction averaged over years indicated that the highest concentration was found in Nainital (8.78 μg g^{-1}) followed by Bhimtal (3.94 μg g^{-1}), Ramtal (2.81 μg g^{-1}), Hanumantal (2.35 μg g^{-1}),

Table 4.34. **Different fraction of Cu (μg g^{-1}) in the sediment of different lakes**

Year / Lakes	W. S. +Exch. (F_1)			NaOAc extractable (F_2)			Organically bound (F_3)			Reducible (F_4)			Residual (F_5)			Total (F_t)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	0.55	0.53	0.54	3.98	3.91	3.94	1.19	1.00	1.10	7.95	7.19	7.57	5.31	4.57	4.94	20.2	18.8	19.5
Naukuchiatal	0.31	0.33	0.32	1.12	1.07	1.10	2.43	2.60	2.51	11.63	11.96	11.79	18.53	15.14	16.83	32.0	29.0	30.5
Punatal	0.35	0.35	0.35	1.27	1.26	1.27	0.42	0.50	0.46	2.69	4.57	3.63	11.63	5.80	8.72	16.3	12.5	14.4
Sitatal	0.39	0.43	0.41	2.46	2.14	2.30	0.43	0.47	0.45	6.49	5.66	6.07	4.34	5.57	4.95	14.1	14.9	14.5
Ramtal	0.40	0.44	0.42	2.80	2.82	2.81	0.41	0.42	0.42	7.92	5.89	6.90	5.31	4.25	4.78	17.6	13.4	15.5
Hanumantal	0.35	0.43	0.39	2.44	2.26	2.35	0.54	0.53	0.53	7.33	6.37	6.85	5.23	5.72	5.47	16.4	15.7	16.0
Nainital	0.71	0.56	0.63	8.76	8.80	8.78	1.05	0.83	0.94	7.20	7.21	7.20	12.34	12.41	12.37	29.5	29.8	29.7
Mean	0.44	0.44		3.26	3.18		0.92	0.91		7.32	6.98		8.95	7.64		20.89	19.15	
Effect	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**
CD (p=0.05)	ns	0.01	0.01	0.05	0.09	0.13	ns	0.06	0.08	0.19	0.36	0.51	0.49	0.92	1.30	0.5	1.0	1.4

Sitatal (2.3 μg g^{-1}), Punatal (1.27 μg g^{-1}) and Naukuchiatal (1.10 μg g^{-1}). The averaged values of Cu-F_2 Fraction in Sitatal and Hanumantal were statistically *at par.*

The values averaged over lakes showed that the concentration of Cu-F_2 fraction during 2004 (3.26 μg g^{-1}) was significantly higher than the concentration in 2004 (3.18 μg g^{-1}).

As regards the effect of interaction between years and lakes, the highest concentration of Cu-F_2 fraction was found in Nainital during 2005 (8.8 μg g^{-1}) and the lowest was noted in Naukuchiatal during 2005 (1.07 μg g^{-1}). As compared to the contents in 2004, significant reduction in Cu-F_2 fraction was noted in Sitatal and Hanumantal during 2005, while the values in Bhimtal, Naukuchiatal, Punatal, Ramtal and Nainital were statistically *at par* during both the years.

4.4.5.3 Organically bound (oxidisable) (Cu-F_3) fraction

On the basis of mean value, the highest concentration of Cu-F_3 fraction was found in Naukuchiatal (2.51 μg g^{-1}), followed by Bhimtal (1.1 μg g^{-1}), Nainital (0.94 μg g^{-1}), Hanumantal (0.53 μg g^{-1}), Punatal (0.46 μg g^{-1}), Sitatal (0.45 μg g^{-1}) and Ramtal (0.42 μg g^{-1}). The averaged values of Cu-F_3 fraction in Punatal, Sitatal and Ramtal were statistically *at par.*

The effect of years was statistically non-significant.

The interaction between years and lakes was also statistically significant. The highest concentration of Cu-F_3 fraction was found in Naukuchiatal during 2005 (2.6 μg g^{-1}) and the lowest was noted in

Ramtal during 2004 (0.41 µg g^{-1}). As compared to 2004, a significant reduction in $Cu\text{-}F_3$ fraction was noted in Bhimtal and Nainital during 2005.

4.4.5.4 Iron and Mn oxide bound (reducible) ($Cu\text{-}F_4$) fraction

The values of $Cu\text{-}F_4$ fraction in sediments of different lakes averaged over years indicated that the highest content of $Cu\text{-}F_4$ fraction was found in Naukuchiatal (11.79 µg g^{-1}) followed by Bhimtal (7.57 µg g^{-1}), Nainital (7.20 µg g^{-1}), Ramtal (6.9 µg g^{-1}), Hanumantal (6.85 µg g^{-1}), Sitatal (6.07 µg g^{-1}) and Punatal (3.36 µg g^{-1}). The averaged values of $Cu\text{-}F_4$ fraction in Ramtal, Hanumantal and Nainital were statistically *at par.*

As regards the effect of years, the content of $Cu\text{-}F_4$ fraction in 2004 (7.32 µg g^{-1}) was significantly higher than the content in 2005 (6.98 µg g^{-1}).

The effect of interaction between years and lakes was statistically significant. The highest concentration of $Cu\text{-}F_4$ fraction was found in Naukuchiatal during 2005 (11.69 µg g^{-1}), while the lowest was noted in Punatal during 2004 (2.69 µg g^{-1}). A significant reduction in the content of $Cu\text{-}F_3$ fraction was noted in Bhimtal, Sitatal and Hanumantal during 2005.

4.4.5.5 Residual ($Cu\text{-}F_5$) fraction

The values averaged over years showed that the highest content of $Cu\text{-}F_5$ fraction was found in Naukuchiatal (16.83 µg g^{-1}) followed by Nainital (12.37 µg g^{-1}), Punatal (8.72 µg g^{-1}), Hanumantal (5.47 µg g^{-1}), Sitatal (4.95 μg g^{-1}), Bhimtal (4.94 μg g^{-1}) and Ramtal (4.78 μg g^{-1}). The averaged values of Cu-F_5 fraction in Bhimtal, Sitatal, Ramtal and Hanumantal were statistically *at par.*

On the basis of mean values, the concentration of Cu-F_5 fraction during 2004 (8.95 μg g^{-1}) was significantly higher than the concentration in 2005 (7.64 μg g^{-1}).

The effect of interaction between years and lakes was also statistically significant. The highest concentration of Cu-F_5 fraction was found in Naukuchiatal during 2004 (18.53 μg g^{-1}) while the lowest was noted in Ramtal during 2005 (4.25 μg g^{-1}). The values in Bhimtal, Sitatal, Ramtal, Hanumantal and Nainital during both the years were statistically *at par.*

4.4.5.6 Total Cu

The values of total Cu content averaged over years indicated that was the highest total copper was found in Naukuchiatal (30.5 μg g^{-1}) followed by Nainital (29.7 μg g^{-1}), Bhimtal (19.5 μg g^{-1}), Hanumantal (16.0 μg g^{-1}), Ramtal (15.5 μg g^{-1}), Sitatal (14.5 μg g^{-1}) and Punatal (14.4 μg g^{-1}). The averaged values of total Copper fraction in Naukuchiatal and Nainital, Punatal and Sitatal and Ramtal and Hanumantal were statistically *at par*, respectively.

The values averaged over lakes showed that the concentration of total copper in 2004 (20.89 μg g^{-1}) was significantly higher than the concentration in 2005 (19.15 μg g^{-1}).

As regards the effect of interaction between years and lakes the highest concentration of total Cu was found in Naukuchiatal during

2004 (32.0 μg g^{-1}) and the lowest was noted in Punatal during 2005 (12.5μg g^{-1}). The values of total Cu in Sitatal, Hanumantal and Nainital during both years were statistically *at par.*

The distribution of Cu among different chemical fractions in lake sediments indicated that the residual (Ni-F_5) fraction was the most dominant fraction (represented 25.32 to 60.40 % of total Cu) followed by the reducible (Cu-F_4) fraction wherein Cu is occuluded by iron and manganese oxides. Lindau and Hossner (1982) reported that especially, Mn oxide have a greater effect on occlusion of Cu and Ni as compared to Fe-oxides. Carbonate bound (Cu-F_2) fraction was the third most dominant fraction which represented 3.59 to 29.59 percentage total Cu in lake sediments. Dudley *et al.*, (1988) also reported that Cu was being adsorbed by fine particles of $CaCO_3$ causing its precipitation as $Cu(OH)_2$ and $Cu(OH)CO_3$. The fraction of Cu associated with organic matter (Cu-F_3) represented 2.73 to 8.53 % of total Cu. Cooper is known to form complexes with both soluble and insoluble organic matter. In general, the lower percentage of Cu associated with organic matter could be attributed to uptake by planktons and/or leaching over years (Lindau and Hossner, 1982).

Water soluble + exchangeable (Cu-F_1) fraction of Cu represented 1.04 to 2.82 % of total Cu. Lindau and Hossner (1982) worked on experimental and natural marshes and reported that on an average <2 % Cu and Ni was associated with this fraction.

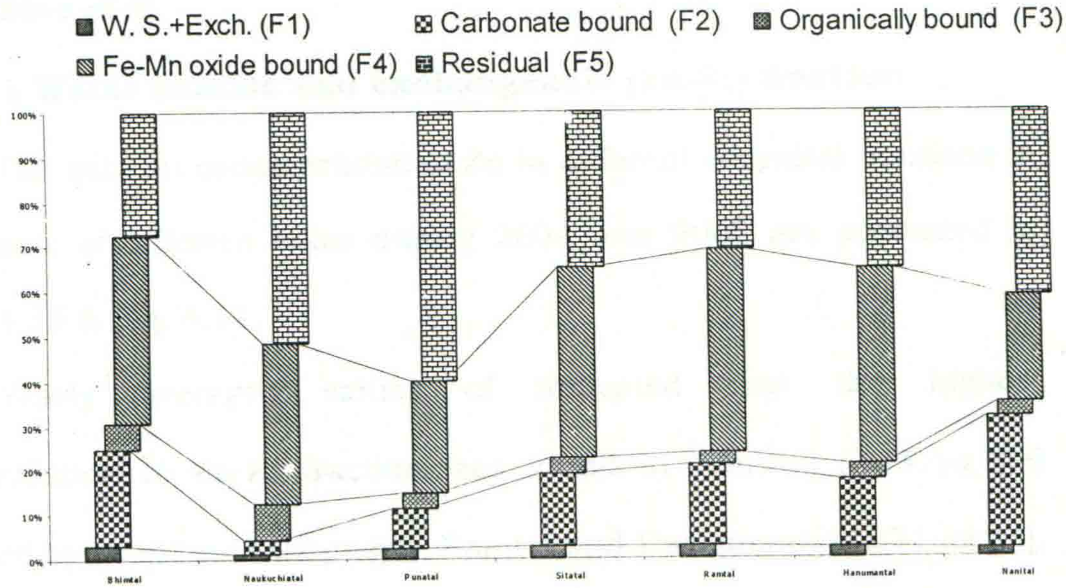

Fig. 4.13 Chemical fractions of Cu as percentage of total metal content in sediments

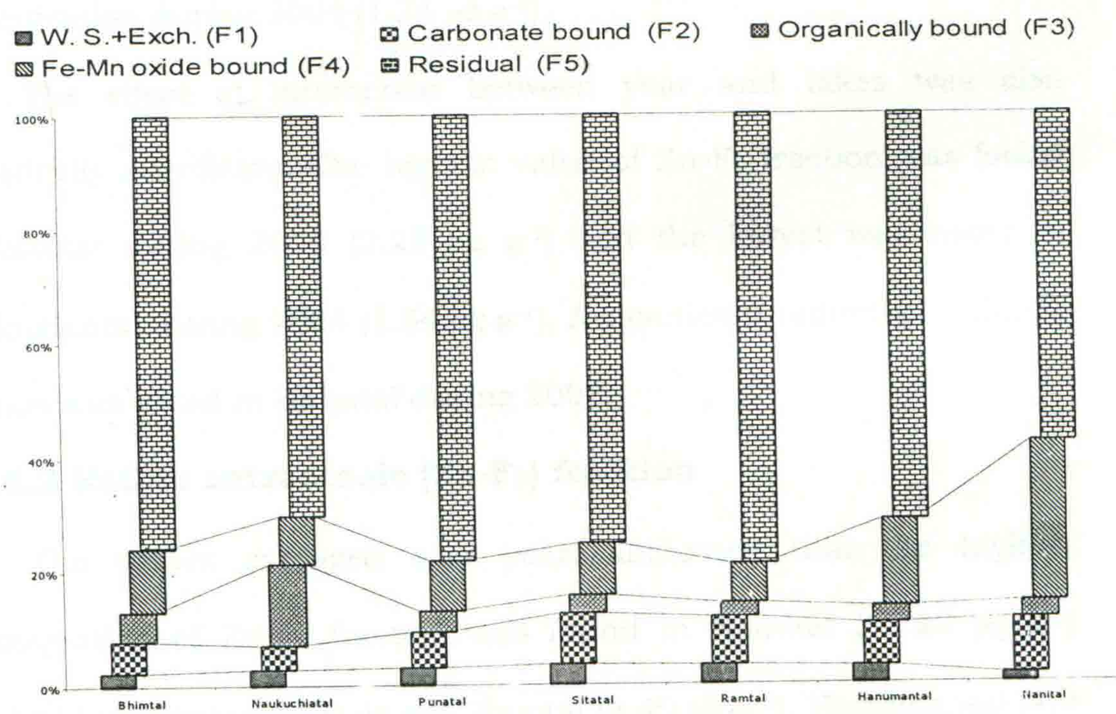

Fig. 4.14 Chemical fractions of Zn as percentage of total metal content in sediments

4.4.6 Zinc (Zn)

4.4.6.1 Water soluble and exchangeable (Zn-F_1) fraction

The data on concentration of Zn in different chemical fractions in sediments of different lakes during 2004 and 2005 are presented in Table 4.35 & Fig. 4.14.

Yearly averaged values of indicated that the highest concentration of Zn-F_1 fraction was found in Nainital (2.14 $\mu g\ g^{-1}$) followed by Bhimtal (1.92 $\mu g\ g^{-1}$), Ramtal and Hanumantal (1.71 $\mu g\ g^{-1}$), Sitatal (1.69 $\mu g\ g^{-1}$), Punatal (1.64 $\mu g\ g^{-1}$) and Naukuchiatal (1.56 $\mu g\ g^{-1}$).

The values averaged over lakes indicated that the concentration of Zn-F_1 during 2005 (1.79 $\mu g\ g^{-1}$) was significantly higher that the concentration during 2004 (1.74 $\mu g\ g^{-1}$).

The effect of interaction between year and lakes was also statistically significant. The highest value of Zn-F_1 fraction was found in Nainital during 2005 (2.25 $\mu g\ g^{-1}$) and the lowest was noted in Naukuchiatal during 2004 (1.54 $\mu g\ g^{-1}$). A significant reduction in Zn-F_1 fraction was noted in Bhimtal during 2005.

4.4.6.2 NaOAc extractable (Zn-F_2) fraction

The values averaged over years indicated that the highest concentration of Zn-F_2 fraction was found in Nainital (13.22 $\mu g\ g^{-1}$) followed by Bhimtal (4.70 $\mu g\ g^{-1}$), Ramtal (4.40 $\mu g\ g^{-1}$), Hanumantal (4.2 $\mu g\ g^{-1}$), Sitatal (4.21 $\mu g\ g^{-1}$). Punatal (3.22 $\mu g\ g^{-1}$) and Naukuchiatal

Table 4.35. Different fraction of Zn (μg g^{-1}) in the sediment from different lakes

Lake / Year	W. S. +Exch. (F_1)			NaOAc extractable (F_2)			Organically bound (F_3)			Reducible (F_4)			Residual (F_5)			Total (F_t)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	1.94	1.89	1.92	4.57	4.83	4.70	4.50	4.42	4.46	9.67	9.23	9.45	61.84	67.48	64.66	85.5	87.9	85.2
Naukuchiatal	1.54	1.58	1.56	2.52	2.54	2.53	8.66	8.49	8.57	4.75	5.26	5.01	41.52	41.41	41.47	52.9	59.3	56.1
Punatal	1.61	1.66	1.64	3.11	3.33	3.22	1.91	2.00	1.96	5.70	4.12	4.91	37.57	46.04	41.80	49.9	57.1	53.5
Sitatal	1.66	1.71	1.69	4.30	4.12	4.21	1.79	1.49	1.64	4.57	4.33	4.45	27.71	43.91	35.81	40.0	55.6	47.8
Ramtal	1.69	1.74	1.71	4.35	4.46	4.40	1.76	1.27	1.51	2.50	4.63	3.56	36.34	45.63	40.99	46.6	55.6	47.8
Hanumantal	1.69	1.72	1.71	4.13	4.42	4.27	1.94	1.67	1.80	3.10	14.55	8.83	36.86	44.54	40.70	47.7	66.5	57.1
Nainital	2.03	2.25	2.14	14.04	13.28	13.66	2.58	4.13	3.36	38.07	41.82	39.95	74.50	87.77	81.13	131.2	149.2	140.2
Mean	1.74	1.79		5.29	5.28		3.31	3.35		9.77	11.99		45.19	53.83		64.4	76.2	
Effect	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L
CD (p=0.05)	0.01	0.03	0.04	ns	0.24	0.33	ns	0.10	0.14	0.42	0.78	1.10	1.65	3.09	4.37	1.8	3.4	4.8

(2.53 μg g^{-1}). The averaged values of $Zn-F_2$ fraction in Sitatal, Ramtal and Hanumantal were statistically *at par.*

As regards the effect of years, there was no statistically significant difference in the values of both the years.

As regards the effect of interaction between years and lakes the highest content of $Zn-F_2$ fraction was found in Nainital during 2004 (14.04 μg g^{-1}) while the lowest was found in Naukuchiatal during 2004 (2.52 μg g^{-1}).

4.4.6.3 Organically bound (oxidisable) ($Zn-F_3$) fraction

The values averaged over years indicated that the highest concentration of $Zn-F_3$ fraction was found in Naukuchiatal (8.57 μg g^{-1}) followed by Bhimtal (4.46 μg g^{-1}), Nainital (3.36 μg g^{-1}), Punatal (1.96 μg g^{-1}), Hanumantal (1.80 μg g^{-1}), Sitatal (1.64 μg g^{-1}) and Ramtal (1.51 μg g^{-1}).

As regards the effect of years, there was no significant difference between the values of $Zn-F_3$ fractions observed in both years.

The effect of interaction between years and lakes was also statistically significant. The highest content of $Zn-F_3$ fraction was found in Naukuchiatal during 2004 (8.66 μg g^{-1}) while the lowest was noted in Ramtal during 2005 (1.25 μg g^{-1}). As compared to 2004, a significant increase in Zn-F3 fraction was noted in Nainital during 2005.

4.4.6.4 Iron and Mn oxide bound (reducible) ($Zn-F_4$) fraction

Yearly averaged values of $Zn-F_4$ fraction indicated that the highest concentration of $Zn-F_4$ fraction was found in Nainital (39.95 μg

g^{-1}) followed by Bhimtal (9.45 μg g^{-1}), Hanumantal (8.83 μg g^{-1}), Naukuchiatal (5.01 μg g^{-1}), Punatal (4.91 μg g^{-1}), Sitatal (4.45 μg g^{-1}) and Ramtal (3.56 μg g^{-1}). The averaged values of Zn-F_4 fraction in Bhimtal and Hanumantal and Naukuchiatal, Punatal and Sitatal were statistically *at par*, respectively.

As regards the effect of years, the concentration of Zn-F_4 fraction during 2005 (11.99 μg g^{-1}) was significantly higher than the concentration during 2004 (9.77 μg g^{-1}).

The effect of interaction between years and lakes was also statistically significant. The highest concentration of Zn-F_4 was found in Nainital during 2005 (41.82 μg g^{-1}) while the lowest was noted in Ramtal during 2004 (2.50 μg g^{-1}).

4.4.6.5 Residual (Zn-F_5) fraction

Yearly averaged values indicated that the highest concentration of Zn-F_5 fraction was found in Nainital (81.13 μg g^{-1}) followed by Bhimtal (64.66 μg g^{-1}), Punatal (41.80 μg g^{-1}), Naukuchiatal (41.47 μg g^{-1}), Ramtal (4.99 μg g^{-1}), Hanumantal (40.70 μg g^{-1}) and Sitatal (35.81 μg g^{-1}). The averaged values of Zn-F_5 fraction in Naukuchiatal, Punatal, Ramtal and Hanumantal were statistically *at par* with each other.

The values averaged over lakes indicated that the concentration of Zn-F_5 fraction during 2005 (53.83 μg g^{-1}) was significantly higher than the concentration during 2004 (45.19 μg g^{-1}).

As regards the statistically significant effect of interaction between years and lakes, the highest concentration of Zn-F_5 fraction was found in Nainital during 2005 (87.77 μg g^{-1}) while the lowest value of noted in Sitatal during 2004 (27.71 μg g^{-1}).

4.4.6.6 Total Zn

On the basis of mean values, the highest content of total Zn was found in Nainital (140.2 μg g^{-1}) followed by Bhimtal (85.2 μg g^{-1}), Hanumantal (57.1 μg g^{-1}), Naukuchiatal (56.1 μg g^{-1}), Punatal (53.5 μg g^{-1}), Ramtal (52.4 μg g^{-1}) and Sitatal (47.8 μg g^{-1}). The averaged values of total Zn in Naukuchiatal and Punatal and Naukuchiatal and Hanumantal were statistically *at par,* respectively.

The values averaged over lakes indicated that the total Zn content during 2005 (76.2 μg g^{-1}) was significantly higher than the content observed during 2004 (64.4 μg g^{-1}).

As regards the statistically significant effect of interaction between lakes and years, the highest concentration of total Zn was found in Nainital during 2005 (149.2 μg g^{-1}) while the lowest was noted in Sitatal during 2004 (40.0 μg g^{-1}).

The relative distribution of different chemical fractions of Zn in lake sediments indicated that the residual (Zn-F_5) fraction was the most dominant fraction as it accounted for 57.85 to 78.24 % of total Zn. This behaviour could be attributed to lithophile and chalcophile nature of Zn. Gupta and Chen (1975) also reported that 23 to 42 % of Zn was locked as residual phase in Los Angeles Harbor sediments.

Zinc associated with reducible (Zn-F_4) fraction represented the second largest fraction which accounted 6.80 to 28.48 % of total Zn. In this pool, Zn is likely to exist in occluded form in Fe-Mn oxides. Carbonate bound ($Zn-F_2$) fraction appeared to be the third most dominant fraction which represent 4.52 to 9.74 % of total Zn in lake sediments. The highest accumulation of this fraction was noted in Nainital which also had the highest accumulation of $CaCO_3$. Like Cu, Zn is also precipitated on the surface of carbonate as hydroxide and/ hydroxide carbonate.

Organically bound ($Zn-F_3$) fraction represented 2.42 to 15.13 % of total Zn in lake sediments. Such a wide variation in this fraction might possibly be related to the variation in the organic matter accumulated in the sediments of different lakes played an important role in retaining Zn. Water soluble and exchangeable ($Zn-F_1$) fraction represented only 1.52 to 3.53 % of total Zn. Lindau and Hossner (1982) also noted that about 4 % of total Zn existed as water soluble and exchangeable fraction in the Pepper Grove and Jamaica Beach substrate samples.

4.4.7 Cadmium (Cd)

The data on concentration of different chemicals fractions of Cd in sediments of different lakes during 2004 and 2005 are presented in Table 4.36 & Fig. 4.15.

4.4.7.1 Water soluble and exchangeable ($Cd-F_1$) fraction

The values averaged over years of $Cd-F_1$ fraction in sediments of different lakes indicated that the highest concentration of $Cd-F_1$ fraction was found in Nainital (0.85 $\mu g\ g^{-1}$) followed by Naukuchiatal (0.83 $\mu g\ g^{-1}$), Bhimtal (0.72 $\mu g\ g^{-1}$), Ramtal (0.62 $\mu g\ g^{-1}$), Punatal (0.61 $\mu g\ g^{-1}$), Hanumantal (0.60 $\mu g\ g^{-1}$) and Sitatal (0.59 $\mu g\ g^{-1}$). The averaged

Table 4.36. **Different fraction of Cd (μg g^{-1}) in the sediment from different lakes**

Year / Lake	W. S. +Exch. (F_1)			NaOAc extractable (F_2)			Organically bound (F_3)			Reducible (F_4)			Residual (F_5)			Total (F_t)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	0.67	0.77	0.72	1.86	1.90	1.88	0.49	0.51	0.50	0.62	0.65	0.63	8.6	9.0	8.8	12.6	12.8	12.7
Naukuchiatal	0.78	0.88	0.83	1.62	1.76	1.69	0.85	0.87	0.86	0.28	0.35	0.32	10.3	10.7	10.5	13.7	14.6	14.1
Punatal	0.56	0.66	0.61	1.75	1.65	1.70	0.34	0.38	0.36	0.35	0.39	0.37	9.5	9.9	9.7	12.7	12.9	12.8
Sitatal	0.53	0.65	0.59	1.73	1.61	1.67	0.33	0.38	0.36	0.35	0.39	0.37	10.5	10.8	10.6	13.4	13.8	13.6
Ramtal	0.57	0.66	0.62	1.81	1.94	1.88	0.34	0.37	0.36	0.27	0.30	0.28	8.1	8.7	8.4	11.1	12.0	11.5
Hanumantal	0.59	0.61	0.60	1.80	1.90	1.85	0.36	0.38	0.37	0.25	0.28	0.26	8.9	9.2	9.1	11.9	12.4	12.1
Nainital	0.73	0.97	0.85	2.44	2.47	2.46	0.40	0.37	0.38	0.31	0.38	0.34	9.5	9.9	9.7	12.8	14.1	13.5
Mean	0.63	0.74		1.86	1.89		0.44	0.47		0.35	0.39		9.3	9.8		12.6	13.2	
Effect	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**
CD (p=0.05)	0.02	0.04	0.05	ns	0.23	ns	0.02	0.04	ns	0.03	0.05	ns	0.2	0.4	ns	0.3	0.5	ns

values of Cd-F_1 fraction in Naukuchiatal and Nainital, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par*, respectively.

As regards the effect of years, the mean concentration of Cd-F_1 fraction in 2005 (0.74 μg g^{-1}) was significantly higher than the mean concentration in 2004 (0.63 μg g^{-1}).

As regards statistically significant effect of interaction between years and lakes, the highest concentration of Cd-F_1 was found in Nainital during 2005 (0.97 μg g^{-1}) while the lowest was noted in Sitatal during 2004 (0.53 μg g^{-1}).

4.4.7.2 NaOAc extractable (Cd-F_2) fraction

The values averaged over years indicated that the highest concentration of Cd-F_2 fraction was found in Nainital (2.46 μg g^{-1}) followed by Bhimtal and Ramtal (1.88 μg g^{-1})) Hanumantal (1.85 μg g^{-1}), Punatal (1.70 μg g^{-1}), Naukuchiatal (1.69 μg g^{-1}) and Sitatal (1.67 μg g^{-1}). The averaged values of Cd-F_2 fraction in Bhimtal, Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par* with ach other.

The effect of years and the interaction between years and lakes were statistically non-significant.

4.4.7.3 Organically bound (oxidisable) (Cd-F_3) fraction

The values averaged over years indicated that the highest concentration of Cd-F_3 fraction was noted in Naukuchiatal (0.86 μg g^{-1})

followed by Bhimtal (0.50 μg g^{-1}), Nainital (0.38 μg g^{-1}), Hanumantal (0.37 μg g^{-1}), Ramtal, Sitatal and Ramtal (0.36 μg g^{-1}). The averaged values in Punatal, Sitatal, Ramtal, Hanumantal and Nainital were statistically *at par.*

As regards the effect of year, the concentration of Cd-F_3 fraction in 2005 (0.4 μg g^{-1}) was significantly higher than the concentration observed in 2004 (0.44 μg g^{-1}).

The effect of interaction between years and lakes was statistically non-significant.

4.4.7.4 Iron and Mn oxide (reducible) (Cd-F_4) fraction

The values averaged over years of Cd-F_4 fraction indicated that the highest concentration of Cd-F_4 was found in Bhimtal (0.63 μg g^{-1}) followed by Punatal and Sitatal (0.37 μg g^{-1}), Nainital (0.34 μg g^{-1}), Naukuchiatal (0.32 μg g^{-1}), Ramtal (0.28 μg g^{-1}) and Hanumantal (0.26 μg g^{-1}). The averaged values of Cd-F_4 fraction in Naukuchiatal and Sitatal; Ramtal and Hanumantal; and Punatal, Sitatal and Nainital were statistically *at par.*

On the basis of mean values, the Cd-F_4 fraction in 2005 (0.39 μg g^{-1}) was significantly higher than the content observed in 2004 (0.35 μg g^{-1}).

The effect of interaction between years and lakes was statistically non- significant.

4.4.7.5 Residual ($Cd-F_5$) fraction

Yearly averaged values of $Cd-F_5$ in sediments of different lakes indicated that the highest concentration of $Cd-F_5$ was found in Sitatal (13.6 μg g^{-1}), Nainital (13.5 μg g^{-1}), Punatal (12.8 μg g^{-1}), Bhimtal (12.7 μg g^{-1}), and Hanumantal (11.5 μg g^{-1}). The averaged values of total Cd in Bhimtal and Hanumantal; and Punatal and Nainital were statistically *at par,* respectively.

On the basis of mean values, the concentration of total Cd in 2005 (13.2 μg g^{-1}) was significantly higher than the concentration observed in 2004 (12.6 μg g^{-1}).

The effect of interaction between years and lakes was statistically non-significant.

4.4.7.6 Total Cd

The values averaged over years of total Cd indicated that the highest content of Cd was found in Naukuchiatal (14.1 μg g^{-1})Bhimtal (12.7 μg g^{-1}) followed by Sitatal (13.6 μg g^{-1}), Nainital (13.5 μg g^{-1}), Punatal (12.8), Hanumantal (12.1 μg g^{-1}) and Ramtal (11.5 μg g^{-1}). The averaged values of total Cd fraction in Bhimtal and Punatal and Sitatal and Nainital were statistically *at par.*

On the basis of mean values, the total Cd in 2005 (13.2 μg g^{-1}) was significantly higher than the content observed in 2004 (12.6 μg g^{-1}).

The effect of interaction between years and lakes was statistically non- significant.

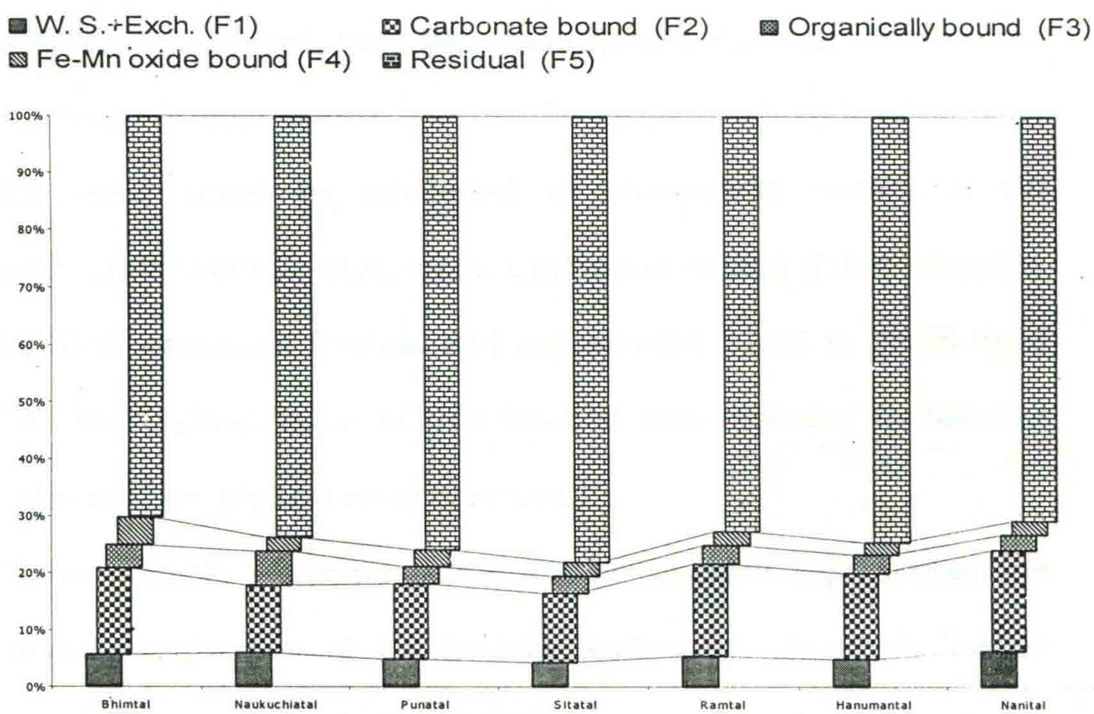

Fig. 4.15 Chemical fractions of Cd as percentage of total metal content in sediments

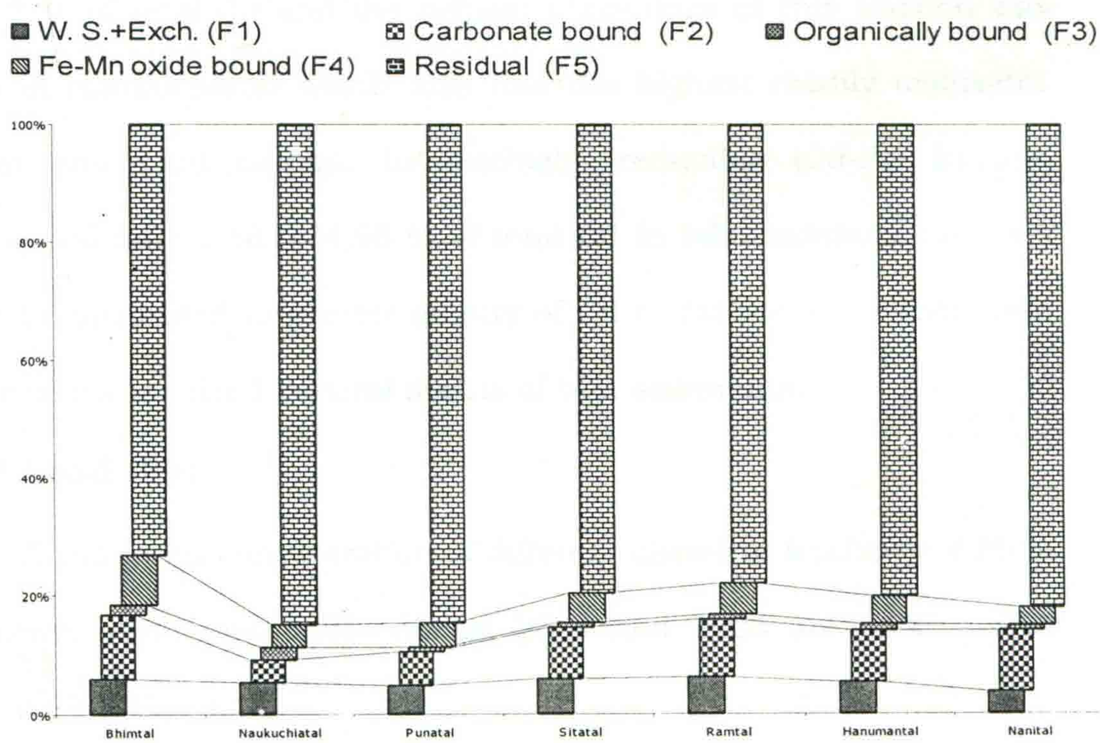

Fig. 4.16 Chemical fractions of Pb as percentage of total metal content in sediments

The relative of Cd distribution of different chemical fractions in lake sediments indicated that the residual (Cd-F_5) fraction was the most dominant fraction as it accounted for 69.22 to 78.10 % of total Cd and the same could be attributed to chalcophile nature of Cd especially, under aquatic ecosystem. Carbonate bound (Cd-F_2) fraction was the most dominant fraction and represented 11.95 to 18.25 % of total Cd. The highest value of this fraction was recorded in Nainital which also had the highest content of $CaCO_3$.

Water soluble + exchangeable (Cd-F_1) fraction represented the third dominant fraction of Cd in lake sediments. Relatively higher amount of Cd in this chemical fraction possibly represented the solubilisation of Cd by soluble organic matter present in water in alkaline pH range. Organically bound (Cd-F_3) fraction represented 2.76 to 6.17 % of total Cd and the highest percentage of this fraction was noted in Naukuchiatal which also had the highest readily oxidisable carbon and total carbon. Interestingly, reducible (Cd-F_4) fraction represented only 2.18 to 4.98 % of total Cd in lake sediment and this might be attributed to greater affinity of Cd to carbonates rather than sesquioxides in mixed mineral matrix of lake sediments.

4.4.8 Lead (Pb)

The data on concentration of different chemical fractions of Pb in sediments of different lakes during 2004 and 2005 are presented in Table 4.37 & Fig. 4.16.

Table 4.37. **Different fraction of Pb (μg g^{-1}) in the sediment from different lakes**

Year / Lake	W. S. +Exch. (F_1)			NaOAc extractable (F_2)			Organically bound (F_3)			Reducible (F_4)			Residual (F_5)			Total (F_t)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	5.54	5.88	5.71	10.39	10.59	10.49	1.49	1.66	1.57	7.99	8.39	8.19	69.6	72.6	71.1	96.0	99.2	97.6
Naukuchiatal	6.27	6.54	6.41	4.65	4.89	4.77	2.41	2.71	2.56	4.50	4.80	4.65	102.6	103.3	103.0	118.9	122.2	120.5
Punatal	5.41	5.61	5.51	6.65	6.82	6.73	0.80	0.93	0.86	4.56	4.82	4.69	96.2	99.2	97.7	113.5	117.4	115.5
Sitatal	5.49	5.76	5.62	8.28	8.34	8.31	0.72	0.79	0.76	4.40	4.79	4.59	75.2	76.9	76.0	94.5	96.6	95.5
Ramtal	5.70	5.84	5.77	8.49	8.79	8.64	0.63	0.76	0.70	4.69	4.87	4.78	69.4	72.4	70.9	88.9	92.7	90.8
Hanumantal	5.09	5.23	5.16	8.42	8.88	8.65	0.88	0.89	0.89	4.39	4.72	4.55	77.3	79.6	78.4	96.0	99.3	97.7
Nainital	6.09	6.23	6.16	16.40	17.40	16.90	1.07	1.54	1.31	4.80	5.13	4.96	133.1	137.1	135.1	161.9	167.4	164.6
Mean	5.66	5.87		9.04	9.39		1.14	1.33		5.05	5.36		89.1	91.6		110.0	113.5	
Effect	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L
CD (p=0.05)	0.10	0.19	ns	0.22	0.41	ns	0.08	0.15	ns	0.20	0.38	ns	1.1	2.0	ns	1.1	2.0	ns

4.4.8.1 Water soluble and exchangeable ($Pb\text{-}F_1$) fraction

The values of $Pb\text{-}F_1$ fraction in sediments of different lakes averaged over year indicated that the highest concentration of $Pb\text{-}F_1$ fraction was found in Naukuchiatal (6.41 $\mu g\ g^{-1}$) followed by Nainital (6.16 $\mu g\ g^{-1}$), Ramtal (5.77 $\mu g\ g^{-1}$), Bhimtal (5.71 $\mu g\ g^{-1}$), Sitatal (5.62 $\mu g\ g^{-1}$), Punatal (5.51 $\mu g\ g^{-1}$) and Hanumantal (5.16 $\mu g\ g^{-1}$). The averaged values of $Pb\text{-}F_1$ fraction in Bhimtal, Sitatal and Ramtal and Punatal and Sitatal were statistically *at par,* respectively.

As regards the effect of years, the mean concentration of $Pb\text{-}F_1$ fraction in 2005 (5.8 $\mu g\ g^{-1}$) was significantly higher than the mean concentration observed in 2004 (5.66 $\mu g\ g^{-1}$). The effect of interaction between years and lakes was not statistically non-significant.

4.4.8.2 NaOAc extractable ($Pb\text{-}F_2$) fraction

The averaged value over years indicated that the highest concentration of $Pb\text{-}F_2$ fraction was found in Nainital (16.90 $\mu g\ g^{-1}$) followed by Bhimtal (10.49 $\mu g\ g^{-1}$), Hanumantal (8.65 $\mu g\ g^{-1}$), Ramtal (8.64 $\mu g\ g^{-1}$), Sitatal (8.31 $\mu g\ g^{-1}$), Punatal (6.73 $\mu g\ g^{-1}$) and Naukuchiatal (4.77 $\mu g\ g^{-1}$). The averaged values of $Pb\text{-}F_2$ fraction in Sitatal, Ramtal and Hanumantal were statistically *at par.*

The effect of years on $Pb\text{-}F_2$ fraction was statistically significant. The concentration of Pb- F_2 fraction observed in 2005 was significantly higher than the mean concentration observed in 2004.

The differences between the two years were statistically significant. The effect of interaction between years and lakes was statistically non- significant.

4.4.8.3 Organically bound (Oxidisable) ($Pb-F_3$) fraction

The values averaged over years indicated that the highest concentration of $Pb-F_3$ fraction was noted in Naukuchiatal (2.56 μg g^{-1}) followed by Bhimtal (1.51 μg g^{-1}), Nainital (1.31 μg g^{-1}), Hanumantal (0.89 μg g^{-1}), Punatal (0.86 μg g^{-1}), Sitatal (0.76 μg g^{-1}) and Ramtal (0.70 μg g^{-1}). The averaged value of $Pb-F_3$ fraction in Ramtal and Sitatal and Sitatal, Punatal and Hanumantal were statistically *at par*, respectively.

As regards the effect of years, the mean concentration of $Pb-F_3$ fraction in 2005 (1.33 μg g^{-1}) was significantly higher than the mean concentration recorded in 2004 (1.14 μg g^{-1}). The effect of interaction between years and lakes on $Pb-_{F3}$ was statistically nOn- significant.

4.4.8.4 Iron and Mn oxide bound (reducible) ($Pb-F_4$) fraction

The values averaged over years showed that the highest concentration of $Pb-F_4$ fraction was found in Bhimtal (8.19 μg g^{-1}) followed by Nainital (4.96 μg g^{-1}), Ramtal (4.78 μg g^{-1}), Punatal (4.69 μg g^{-1}), Naukuchiatal (4.65 μg g^{-1}), Sitatal (4.56 μg g^{-1}) and Hanumantal (4.55 μg g^{-1}). Averaged values of $Pb-F_4$ fraction in Naukuchiatal, Punatal, Sitatal, Ramtal, Hanumantal and Nainital were statistically *at par*. The mean concentration of $Pb-F_4$ fraction in 2005 (5.36 μg g^{-1}) was significantly higher than the value recorded in 2004 (5.05 μg g^{-1}).

The effect of interaction between years and lakes was statistically non- significant.

4.4.8.5 Residual (Pb-F_5) fraction

The values of Pb-F_5 fraction in sediments of different lakes averaged over years indicated that the highest concentration of Pb-F_5 fraction was found in Nainital (135.1 μg g^{-1}) followed by Naukuchiatal (103.0 μg g^{-1}), Punatal (97.7 μg g^{-1}), Hanumantal (78.4 μg g^{-1}), Sitatal (76.0 μg g^{-1}), Bhimtal (71.1 μg g^{-1}) and Ramtal (70.9 μg g^{-1}). The averaged values of Pb-F_5 in Ramtal and Bhimtal were statistically *at par*. The mean concentration of Pb-F_5 fraction in year 2005 (91.6 μg g^{-1}) was significantly higher than the values observed in 2004 (89.1 μg g^{-1}). The interaction effect between years and lakes was statistically non-significant.

4.4.8.6 Total (Pb-F_t)

The values averaged over years indicated that the highest concentration of Pb-F_t was found in Nainital (164.6 μg g^{-1}) followed by Naukuchiatal (120.5 μg g^{-1}), Punatal (115.5 μg g^{-1}), Hanumantal (97.7 μg g^{-1}), Bhimtal (97.6 μg g^{-1}), Sitatal (95.5 μg g^{-1}) and Ramtal (90.8 μg g^{-1}). The averaged values of Pb-F_t in Bhimtal and Hanumantal were statistically *at par*. The mean concentration of Pb-F_t observed in 2005 (113.5 μg g^{-1}) was significantly higher than the value recorded in 2004 (110.0 μg g^{-1}). The effect of interaction between years and lakes was statistically non-significant.

The relative distribution of different chemical fractions of Pb in lake sediments revealed that the residual (Pb-F_5) fraction was the most dominant fraction as it accounted for 72.92 to 85.42 % of total Pb. This behaviour could be attributed to both lithophile and chalcophile nature of Pb. Like Cd, carbonate bound (Pb-F_2) fraction was the second most dominant fraction which accounted for 3.96 to 10.75 % of total Pb in lake sediments.

Water soluble + exchangeable (Pb-F_1) fraction was the third most dominant fraction which accounted 3.74 to 6.35 % of total Pb in lake sediments. Reducible (Pb-F_4) fraction represented 3.01 to 8.39 % of total Pb in lake sediments. Thus, like Cd, Pb also showed higher preference to carbonate minerals rather than Fe-Mn oxides in lake sediments. Organically bound (Pb-F_3) fraction represented 0.80 to 2.24 % of total Pb. Lead is known to form insoluble and stable chelates with organic matter. However, under submergence condition the presence of organic matter possibly solubilized Pb and thus, the fraction reported in this study indicated only insoluble and stable fraction of Pb associated with organic matter.

4.4.9 Calcium (Ca)

The data on concentration of different chemical fractions of Ca in sediments of different lakes during 2004 and 2005 are presented in Table 4.38 & Fig. 4.17.

4.4.9.1 Water soluble and exchangeable (Ca-F_1) fraction

The values averaged over years of Ca-F_1 fraction was the highest in Nainital (409 μg g^{-1}) followed by Bhimtal (206 μg g^{-1}), Punatal (185 μg

Table 4.38. Different fraction of Ca (μg g^{-1}) in the sediment from different lakes

Year / Lake	W. S. +Exch. (F_1)			NaOAc extractable (F_2)			Organically bound (F_3)			Reducible (F_4)			Residual (F_5)			Total (F_t)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	157	254	206	274	301	288	500	603	551	9	10	10	592	351	472	1533	1518	1526
Naukuchiatal	99	125	112	68	65	66	27	32	30	15	16	16	78	81	80	287	319	303
Punatal	222	149	185	68	71	70	25	33	29	23	24	24	76	65	71	414	343	378
Sitatal	63	105	84	33	25	29	13	11	12	24	25	25	114	112	113	247	279	263
Ramtal	67	95	81	29	26	27	14	14	14	28	29	29	123	125	124	262	290	276
Hanumantal	62	95	79	35	24	30	10	13	12	27	28	27	189	155	172	323	315	319
Nainital	394	424	409	6818	6481	6650	1483	1534	1508	853	862	858	10595	11140	10868	20143	20441	20292
Mean	152	178		1046	999		296	320		140	142		1681	1719		3316	3358	
Effect	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L	Year (Y)	Lake (L)	Y x L
CD (p=0.05)	3	5	8	ns	123	ns	23	43	ns	ns	5	ns	ns	223	315	ns	256	ns

g^{-1}), Naukuchiatal (112 μg g^{-1}), Sitatal (84 μg g^{-1}), Ramtal (81 μg g^{-1}) and Hanumantal (79 μg g^{-1}). The averaged values of Ca-F_1 fraction in Sitatal and Ramtal, and Hanumantal and Ramtal were statistically at par.

As regards the effect of years, the mean concentration of Ca-F_1 in 2005 (178 μg g^{-1}) was significantly higher than the value observed in 2004 (152 μg g^{-1}). The effect of interaction between years lakes indicated that the highest concentration of Ca-F_1 was found in Nainital during 2005 (424 μg g^{-1}) while the lowest was noted in Hanumantal during 2004 (0.62 μg g^{-1}).

4.4.9.2 NaOAc extractable (Ca-F_2) fraction

The values of Ca-F_2 fraction averaged over years indicated that the highest concentration of this fraction was noted in Nainital (6650 μg g^{-1}) followed by Bhimtal (288 μg g^{-1}), Punatal (70 μg g^{-1}), Naukuchiatal (66 μg g^{-1}), Hanumantal (30 μg g^{-1}), Sitatal (29 μg g^{-1}) and Ramtal (27 μg g^{-1}). The averaged values of Ca-F_2 fraction in Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par.*

The effects of years and interaction between years and lakes on Ca-F_2 fraction were found to be statistically non- significant.

4.4.9.3 Organically bcund (oxidisable) (Ca-F_3) fraction

On the basis of mean values, the highest concentration of Ca-F_3 fraction was found in Nainital (1508 μg g^{-1}) followed by Bhimtal (551 μg g^{-1}), Naukuchiatal (30 μg g^{-1}), Punatal (29 μg g^{-1}), Ramtal (14 μg g^{-1}) and Sitatal and Hanumantal (12 μg g^{-1}). The averaged values of Ca-F_3 fraction in Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par.*

The averaged values over lakes showed that the concentration of Ca-F_3 during 2005 (320 µg g^{-1}) was significantly higher than that in 2004 (296 µg g^{-1}).

The interaction, between years and lakes was statistically non-significant.

4.4.9.4 Iron and Mn oxide bound (reducible) (Ca-F_4)

The values of Ca-F_4 fraction in sediments of different lakes averaged over years indicated that the highest content of Ca-F_4 fraction was found in Nainital (858 µg g^{-1}) followed by Ramtal (29 µg g^{-1}), Hanumantal (27 µg g^{-1}), Sitatal (25 µg g^{-1}), Punatal (24 µg g^{-1}), Naukuchiatal (16 µg g^{-1}) and Bhimtal (10 µg g^{-1}). The averaged values of Ca-F_4 Fraction in Punatal, Sitatal, and Hanumantal; and Ramtal, Sitatal and Hanumantal were statistically *at par,* respectively.

The mean concentrations of Ca-F_4 fraction in both the years were found to be statistically similar.

The effect of interaction between years and lakes on Ca-F_4 fraction was statistically non- significant.

4.4.9.5 Residual (Ca-F_5) fraction

The values averaged over years showed that the highest content of Ca-F_5 fraction was found in Nainital (10868 µg g^{-1}) followed by Bhimtal (472 µg g^{-1}), Hanumantal (172 µg g^{-1}), Ramtal (124 µg g^{-1}), Sitatal (113 µg g^{-1}), Naukuchiatal (80 µg g^{-1}) and Punatal (71 µg g^{-1}). The mean values of Ca-F_5 Fraction in Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par*.

As regards the effect of years, there was no significant difference between concentrations of Ca-F_5 fraction recorded in 2003-04 and 2004-05.

The effect of interaction between years and lakes on Ca-F_5 fraction was significant. The highest concentration of Ca-F_5 was found in Nainital during 2005 (11140 $\mu g\ g^{-1}$) while the lowest value was noted in Punatal during 2005 (65 $\mu g\ g^{-1}$).

4.4.9.6 Total Ca

The values of total calcium content averaged over years indicated that the highest total calcium was found in Nainital (20292 $\mu g\ g^{-1}$) followed by Bhimtal (1526 $\mu g\ g^{-1}$), Punatal (378 $\mu g\ g^{-1}$), Hanumantal (319 $\mu g\ g^{-1}$), Naukuchiatal (303 $\mu g\ g^{-1}$), Ramtal (276 $\mu g\ g^{-1}$) and Sitatal (263 $\mu g\ g^{-1}$). The mean values of total calcium Fraction in Naukuchiatal, Punatal, Sitatal, Ramtal and Hanumantal were statistically *at par* with each other.

The effects of years and the interaction between years and lakes on total Ca content were statistically non- significant.

The relative distribution of different chemical fractions of Ca in lake sediments revealed that the residual (Ca-F_5) fraction was the most dominant fraction as it accounted for 18.63 to 53.85 % of total Ca. Carbonate bound (Ca-F_2) fraction showed 9.34 to 32.77 % of total Ca and the highest value of this fraction was noted in Nainital which also had the highest content of $CaCO_3$. Organically bound (Ca-F_3) fraction showed a wide variation and accounted for 3.97 to 39.51 % of total Ca indicating thereby the importance of nature of organic matter in lake sediments. Reducible (Ca-F_4) fraction of Ca was of minor importance and represented only 0.63 to 10.38 % of total Ca.

4.4.10 Magnesium (Mg)

The data on concentration of different chemical fractions of Mg in sediments of different lakes during 2004 and 2005 are presented in Table 4.39 & Fig. 4.18.

4.4.10.1 Water soluble and exchangeable (Mg-F_1) fraction

The values of Mg-F_1 fraction averaged over years indicated that this fraction was the highest in Nainital (162 $\mu g\ g^{-1}$) followed by Naukuchiatal and Punatal (119 $\mu g\ g^{-1}$), Bhimtal (82 $\mu g\ g^{-1}$), Sitatal (75 $\mu g\ g^{-1}$), Ramtal (65 $\mu g\ g^{-1}$) and Hanumantal (61 $\mu g\ g^{-1}$). The mean values of Mg-F_1 fraction in Ramtal and Hanumantal were statistically at par.

As regards the years, the mean concentration of Mg-F_1 in 2005 (100 $\mu g\ g^{-1}$) was significantly higher than that in 2004 (95 $\mu g\ g^{-1}$). The interaction between years and lakes was statistically non-significant.

4.4.10.2 NaOAc extractable (Mg-F_2) fraction

The values of Mg-F_2 fraction averaged over years showed that value of this fraction was the highest in Nainital (207 $\mu g\ g^{-1}$) followed by Bhimtal (153 $\mu g\ g^{-1}$), Naukuchiatal (105 $\mu g\ g^{-1}$), Hanumantal and Sitatal (58 $\mu g\ g^{-1}$), Punatal (52 $\mu g\ g^{-1}$) and Ramtal (50 $\mu g\ g^{-1}$). The mean values of Mg-F_2 fraction in Punatal and Ramtal were statistically *at par.*

Table 4.39. ***Different fraction of Mg ($\mu g\ g^{-1}$) in the sediment from different lakes***

Lake / Year	W. S. +Exch. (F_1)			NaOAc extractable (F_2)			Organically bound (F_3)			Reducible (F_4)			Residual (F_5)			Total (F_t)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Bhimtal	78	85	82	152	153	153	73	78	75	98	100	99	3915	3981	3948	4315	4397	4356
Naukuchiatal	116	121	119	104	107	105	41	45	43	137	139	138	5000	5042	5021	5398	5456	5427
Punatal	116	123	119	49	56	52	27	33	30	61	66	63	3431	3564	3497	3684	3841	3763
Sitatal	74	77	75	57	59	58	453	474	463	57	61	59	865	885	875	1506	1556	1531
Ramtal	62	69	65	49	51	50	426	439	433	41	46	43	832	849	841	1410	1455	1432
Hanumantal	58	63	61	57	59	58	494	485	490	65	69	67	783	786	784	1458	1462	1460
Nainital	160	164	162	202	212	207	2073	2137	2105	274	279	277	5247	5377	5312	7956	8169	8062
Mean	95	100		96	100		512	527		105	108		2868	2926		3675	3762	
Effect	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**	**Year (Y)**	**Lake (L)**	**Y x L**
CD (p=0.05)	3	5	ns	2	4	ns	13	24	ns	2	4	ns	89	166	ns	ns	165	ns

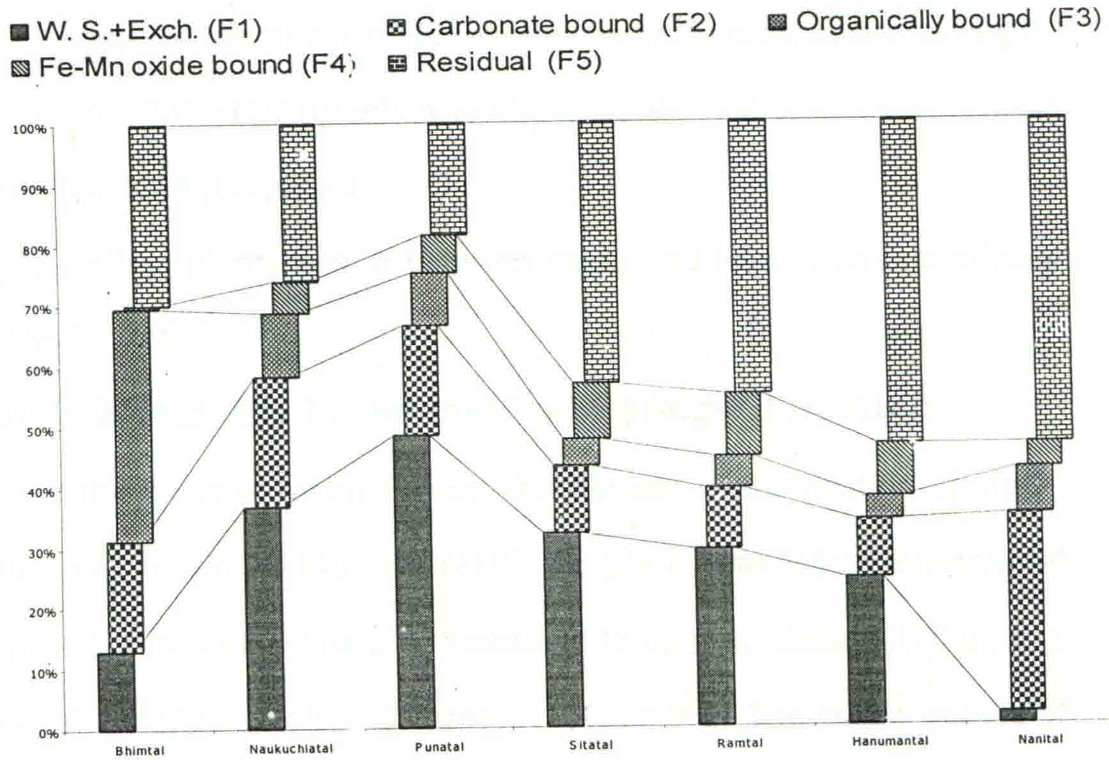

Fig. 4.17 Chemical fractions of Ca as percentage of total metal content in sediments

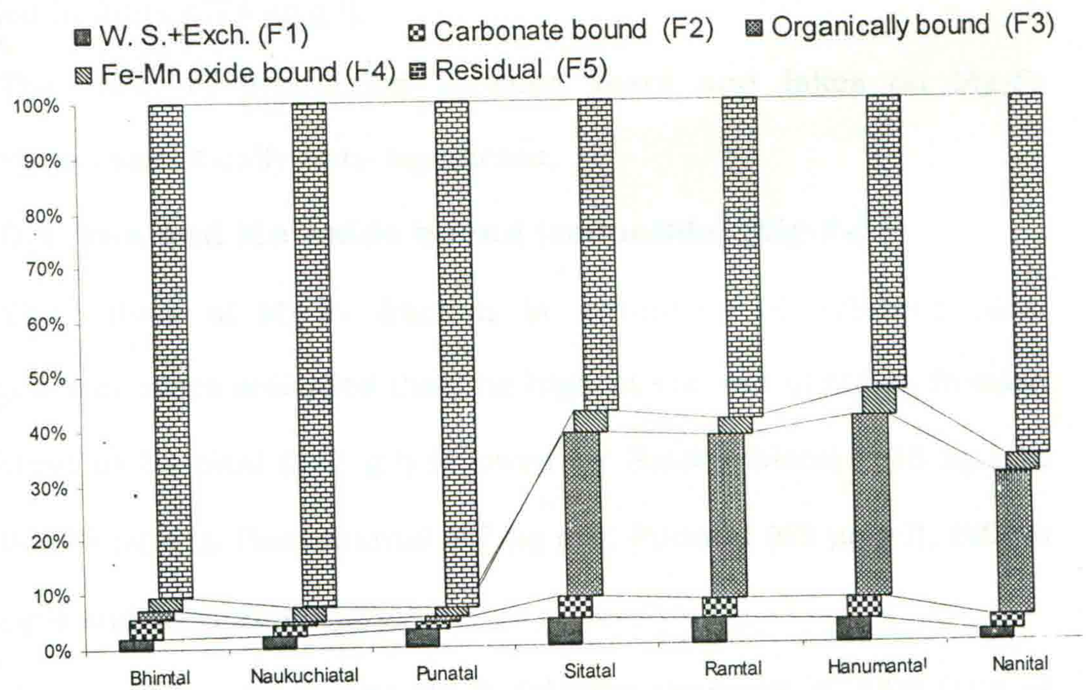

Fig. 4.18 Chemical fractions of Mg as percentage of total metal content in sediments

As regards the effect of years, the mean concentration of Mg-F_2 recorded in 2005 (100 μg g^{-1}) was significantly higher than the value observed in 2004 (96 μg g^{-1}).

The effect of interaction between years and lakes was statistically non- significant.

4.4.10.3 Organically bound (oxidisable) (Mg-F_3) fraction

On the basis of mean values, the highest concentration of Mg-F_3 fraction was found in Nainital (2105 μg g^{-1}) followed by Hanumantal (490 μg g^{-1}), Sitatal (463 μg g^{-1}), Ramtal (433 μg g^{-1}), Bhimtal (75 μg g^{-1}), Naukuchiatal (43 μg g^{-1}) and Punatal (30 μg g^{-1}). The mean values of Mg-F_3 fraction in Naukuchiatal and Punatal were statistically *at par.*

The values averaged over lakes showed that the concentration of Mg-F_3 during 2005 (527 μg g^{-1}) was significantly higher than the value recorded in 2004 (274 μg g^{-1}).

The effect of interaction between years and lakes on Mg-F_3 fraction was statistically non- significant.

4.4.10.4 Iron and Mn oxide bound (reducible) (Mg-F_4)

The values of Mg-F_4 fraction in sediments of different lakes averaged over years indicated that the highest content of Mg-F_4 fraction was found in Nainital (277 g^{-1}) followed by Naukuchiatal (138 μg g^{-1}), Bhimtal (99 μg g^{-1}), Hanumantal (67 μg g^{-1}), Punatal (63 μg g^{-1}), Sitatal (59 μg g^{-1}) and Ramtal (43 μg g^{-1}.

The mean concentration Mg-F_4 fraction observed in 2005 (108 μg g^{-1}) was found to be significantly higher than the value recorded in 2004 (105 μg g^{-1}).

The effect of interaction between years and lakes was statistically non- significant.

4.4.10.5 Residual (Mg-F_5) fraction

The values of this fraction averaged over years showed that the highest content of Mg-F_5 fraction was found in Nainital (5312 μg g^{-1}) followed by Naukuchiatal (5021 μg g^{-1}), Bhimtal (3948 μg g^{-1}), Punatal (3497 μg g^{-1}), Sitatal (875 μg g^{-1}), Hanumantal (784 μg g^{-1}) and Ramtal (841 μg g^{-1}). The averaged values of Mg-F_5 Fraction in Sitatal, Ramtal and Hanumantal were statistically *at par.*

As regards the effect of years, the mean concentration Mg-F_5 fraction in 2005 (5377 μg g^{-1}) was found to be significantly higher than the value recorded in 2004 (5247 μg g^{-1}).

The effect of interaction between years and lakes was found to be statistically not significant.

4.4.10.6 Total Mg

The values of total magnesium content averaged over years indicated that was the highest total magnesium was found in Nainital (8062 μg g^{-1}) followed by Naukuchiatal 5427 μg g^{-1}), Bhimtal (4356 μg g^{-1}), Punatal (3762 μg g^{-1}), Sitatal (1531 μg g^{-1}), Hanumantal (1460 μg g^{-1}) and Ramtal (1432 μg g^{-1}). The averaged values of total magnesium fraction in Sitatal, Ramtal and Hanumantal were statistically *at par* with each other.

The relative distribution of different chemical fractions of Ca in lake sediments revealed that the residual (Mg-F_5) fraction was the most dominant fraction as it represented for 53.71 to 92.95 % of total Mg. This was anticipated in view of lithophile nature of this alkaline earth metal. Organically bound ($Mg-F_3$) fraction represented 0.83 to 33.25 % of total Mg. The wide range of variations in organically bound Mg again impressed upon the importance of nature of organic matter in lake sediments. Water soluble + exchangeable ($Mg-F_1$) fraction represented only 1.87 to 4.91 % of the total Mg in lake sediments. Reducible ($Mg-F_4$) fraction represented 1.69 to 4.58 % of total Mg.

Carbonate bound ($Mg-F_2$) fraction represented 1.39 to 3.99 % of total Mg. This kind of distribution indicated greater preference of Mg for organic ligands than its tendency to get precipitated as carbonate minerals.

4.5 Correlation studies

4.5.1 Relation between physico-chemical properties of water and concentration of cations and anions in waters

Simple correlation coefficients (r) computed between the physico-chemical properties and concentration of different cations and anions in waters from different lakes are presented in Table-4.40.

The concentrations of NH_4^+-N, K^+, Na^+, Ca^{2+} and Mg^{2+} in waters were significantly and positively correlated with pH, electrical conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD) and alkalinity of waters at p=0.01. The concentrations of NH_4^+-N, K^+, Na^+, Ca^{2+} and Mg^{2+} were significantly and negatively correlated with dissolved oxygen (DO) at p=0.01.

The concentrations of NO_3^--N, PO_4^{2-}-P, SO_4^{2-}-S and Cl^- in waters were also significantly and positively correlated with pH, electrical

Table 4.40. Relationship between physico-chemical properties of water and concentration of cations and anions in waters from different lakes

	NH_4^+-N	NO_3^--N	PO_4^{2-}-P	SO_4^{2-}-S	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-
pH	0.842**	0.877**	0.828**	0.774**	0.799**	0.844**	0.842**	0.735**	0.824**
EC	0.877**	0.893**	0.974**	0.976**	0.880**	0.931**	0.877**	0.793**	0.803**
DO	-0.882**	-0.875**	-0.947**	-0.937**	-0.872**	-0.921**	-0.882**	-0.814**	-0.817**
BOD	0.848**	0.802**	0.796**	0.737**	0.873**	0.887**	0.848**	0.801**	0.753**
COD	0.883**	0.871**	0.932**	0.925**	0.874**	0.959**	0.883**	0.860**	0.800**
Alkalinity	0.906**	0.903**	0.907**	0.880**	0.909**	0.902**	0.906**	0.792**	0.794**

**Significant at p=0.01

Table 4.41. Relationship between physico-chemical properties of water and concentration of heavy metals in waters from different lakes

	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
pH	0.389**	0.555**	0.009	0.842**	0.381**	0.890**	0.569**	0.709**
EC	0.385**	0.648**	-0.053	0.879**	0.224	0.910**	0.562**	0.815**
DO	-0.267*	-0.588**	0.024	-0.872**	-0.264*	-0.907**	-0.518**	-0.732**
BOD	0.515**	0.743**	0.099	0.757**	0.601**	0.897**	0.549**	0.774**
COD	0.339**	0.641**	0.020	0.876**	0.348**	0.922**	0.553**	0.791**
Alkalinity	0.441**	0.733**	0.102	0.817**	0.398**	0.900**	0.659**	0.826**

*Significant at p=0.05; **Significant at p=0.01

Table 4.42 Relationship between physico-chemical properties of sediment and different chemical fractions of Cr in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Clay	-0.361	0.229	-0.628*	-0.261	-0.202	-0.268
Silt	0.288	0.048	0.471	0.727**	-0.172	0.105
Sand	0.336	-0.268	0.590*	0.120	0.266	0.275
pH	0.417	0.856**	0.431	0.592*	0.115	0.351
EC	0.279	0.836**	0.460	0.385	0.105	0.287
ROC	0.744**	0.388	0.917**	0.327	0.669**	0.727**
TC	0.589*	0.042	0.791**	0.189	0.528	0.543*
$CaCO_3$	0.287	0.889**	0.294	0.209	0.275	0.365

*Significant at p=0.05; **Significant at p=0.01

conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD) and alkalinity of waters at p=0.01. The concentrations of NO_3^--N, PO_4^{2-}-P, SO_4^{2-}-S were significantly and negatively correlated with dissolved oxygen (DO) at p=0.01.

4.5.2 Relation between physico-chemical properties of water and concentration of heavy metals in waters

Simple correlation coefficients (r) computed between the physico-chemical properties and concentrations of different heavy metals in waters from different lakes are presented in Table-4.41.

The concentrations of Cr, Mn, Ni, Cu, Zn, Cd and Pb were significantly and positively correlated with pH, electrical conductivity (EC), biological oxygen demand (BOD), Chemical oxygen demand (COD) and alkalinity of waters at p=0.01. The concentrations of Cr, Mn, Ni, Cu, Zn, Cd and Pb were significantly and negatively correlated with dissolved oxygen (DO) at p=0.01.

The concentration of Fe in waters was statistically not correlated with physico-chemical properties of waters considered here.

4.5.3 Relation between physico-chemical properties of sediment sand the content of different chemical fractions of metals in sediments

The values of simple correlation coefficients (r) computed between physico-chemical and the concentration of different chemical fractions of metals in sediments are presented in Table 4.42 to 4.51.

4.5.3.1 Chromium (Cr)

As shown in Table-4.42, the water soluble + exchangeable (Cr-F_1) fraction in sediments was significantly and positively correlated with readily oxidizable carbon (ROC) and total carbon (TC) of the sediments at p=0.01 and p=0.05, respectively.

The carbonates bound (Cr-F_2) fraction in the sediments of different lakes showed a significant and positive correlation with pH and electrical conductivity (EC) of the sediments at p=0.01 and $CaCO_3$ content at p=0.05, respectively.

The Organically bound (Cr-F_3) fraction in sediments was significantly and positively correlated with readily oxidizable carbon (ROC) and total carbon (TC) of the sediments at p=0.01 and with sand content at p=0.05, respectively. While the concentration of Cr-F_3 fraction was significantly and negatively correlated with clay content of sediments at p=0.05.

The Fe-Mn oxide bound (Cr-F_4) fraction was significantly and positively correlated with silt content and pH of the sediments at p=0.01 and 0.05, respectively.

The residual (Cr-F_5) fraction was significantly and positively correlated with readily oxidizable carbon (ROC) of the sediments at p=0.01. While the concentration of Cr-F_5 fraction was statistically not correlated with clay, silt and sand content, pH, EC, TC and $CaCO_3$ content of sediments.

The total chromium content was significantly and positively correlated with readily oxidizable carbon (ROC) and total carbon (TC) of the sediments at p=0.01 and 0.05, respectively.

4.5.3.2 Manganese (Mn)

The data in Table 4.43 showed that the water soluble + exchangeable ($Mn-F_1$) fraction in sediments was significantly and positively correlated with pH, EC and $CaCO_3$ of the sediments at p=0.01 but negatively correlated with sand content at p=0.05.

There was a significant and positive correlation between carbonate bound ($Mn-F_2$) fraction in sediment with pH, EC and $CaCO_3$ of the sediments at p=0.01.

The Organically bound ($Mn-F_3$) fraction in sediment was significantly and positively correlated with sand, readily oxidizable carbon (ROC) and total carbon (TC) contents of the sediments at p=0.01 but negatively correlated with clay % in sediments at p=0.01.

The Fe-Mn oxide bound ($Mn-F_4$) fraction was significantly and positively correlated with pH, EC and $CaCO_3$ content of the sediments at p=0.01.

The residual ($Mn-F_5$) fraction was significantly and positively correlated with sand, readily oxidizable carbon (ROC) and TC content of the sediments at p=0.01 but negatively correlated with clay content at p=0.05.

The total magnesium content was significantly and positively correlated with readily oxidisable carbon (ROC) and total carbon (TC) at p=0.01 and with $CaCO_3$ content of sediments at p=0.05, respectively.

Table 4.43 Relationship between physico-chemical properties of sediment and different chemical fractions of Mn in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Clay	0.519	0.414	-0.855**	0.156	-0.633*	-0.302
Silt	-0.177	-0.174	0.226	-0.109	-0.004	-0.122
Sand	-0.538*	-0.422	0.903**	-0.148	0.709**	0.367
pH	0.809**	0.818**	-0.186	0.713**	-0.003	0.345
EC	0.793**	0.878**	-0.100	0.720**	0.168	0.512
ROC	0.125	0.265	0.904**	0.528	0.953**	0.862**
TC	-0.234	-0.094	0.974**	0.205	0.910**	0.667**
$CaCO_3$	0.935**	0.979**	-0.210	0.828**	0.143	0.555*

*Significant at p=0.05; **Significant at p=0.01

Table 4.44 Relationship between physico-chemical properties of sediment and different chemical fractions of Fe in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Clay	0.219	0.421	-0.841**	-0.164	-0.776**	-0.859**
Silt	0.073	-0.316	0.268	0.838**	0.049	0.215
Sand	-0.262	-0.396	0.876**	-0.014	0.856**	0.909**
pH	0.905**	0.749**	-0.110	0.666**	-0.617*	-0.441
EC	0.916**	0.840**	-0.052	0.429	-0.496	-0.351
ROC	0.387	0.281	0.928**	0.133	0.590*	0.729**
TC	0.045	-0.064	0.975**	0.011	0.799**	0.892**
$CaCO_3$	0.922**	0.976**	-0.158	0.210	-0.570*	-0.469

*Significant at p=0.05; **Significant at p=0.01

4.5.3.3 Iron (Fe)

As shown in Table-4.44, the water soluble + exchangeable (Fe-F_1) fraction in sediments was significantly and positively correlated with pH, EC and $CaCO_3$ of the sediments at p=0.01.

A significant and positive correlation was recorded between carbonate bound (Fe-F_2) fraction in sediments and pH, EC and $CaCO_3$ of the sediments at p=0.01.

The Organically bound (Fe-F_3) fraction in sediment was significantly and positively correlated with sand, readily oxidizable carbon (ROC) and total carbon (TC) contents of the sediments at p=0.01 but negatively correlated with clay content.

The Fe-Mn oxide bound (Fe-F_4) fraction was significantly and positively correlated with silt content and pH of the sediments at p=0.01.

The residual (Fe-F_5) fraction was significantly and positively correlated with sand and TC content of the sediments at p=0.01 and with readily oxidizable carbon (ROC) at p=.05, respectively. The concentration of Fe-F_5 fraction was significantly and negatively correlated with clay content of sediments at p=0.01 and with pH and $CaCO_3$ content at p=0.05, respectively.

The total iron content was significantly and positively correlated with sand content, readily oxidizable carbon (ROC) and total carbon (TC) of the sediments but negatively correlated with clay content of sediments at p=0.01, respectively.

4.5.3.4 Nickel (Ni)

As shown in Table-4.45, the water soluble + exchangeable (Ni-F_1) fraction in sediment was significantly and positively correlated with EC and $CaCO_3$ of the sediments at p=0.01 and with pH at p=0.05, respectively.

A significant and positive correlation was noted between carbonate bound (Ni-F_2) fraction in sediment and with pH, EC and $CaCO_3$ of the sediments at p=0.01.

The Organically bound (Ni-F_3) fraction in sediment did not show any significant correlation with any physico-chemical property of the sediments.

The Fe-Mn oxide bound (Ni-F_4) fraction was significantly and positively correlated with pH, EC and $CaCO_3$ content of the sediments at p=0.05.

The residual (Ni-F_5) fraction was significantly and positively correlated with EC and $CaCO_3$ content of the sediments at p=0.05. The concentration of Ni-F_5 fraction was significantly and negatively correlated with silt content of sediments at p=0.05.

The total Ni content was significantly and positively correlated with EC and $CaCO_3$ content at p=0.01 and with pH of sediments at p=0.05, respectively.

Table 4.45 Relationship between physico-chemical properties of sediment and different chemical fractions of Ni in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Clay	0.368	0.111	-0.126	0.144	0.321	0.273
Silt	-0.388	0.389	0.232	0.158	-0.554*	-0.320
Sand	-0.320	-0.216	0.086	-0.198	-0.228	-0.229
pH	0.650*	0.948**	0.157	0.629*	0.407	0.593*
EC	0.757**	0.872**	0.104	0.637*	0.532*	0.672**
ROC	0.356	0.300	0.236	0.317	0.392	0.442
TC	0.026	0.005	0.136	0.028	0.114	0.118
$CaCO_3$	0.927**	0.770**	0.057	0.650*	0.772*	0.840**

*Significant at p=0.05; **Significant at p=0.01

Table 4.46 Relationship between physico-chemical properties of sediment and different chemical fractions of Cu in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Clay	0.364	0.424	-0.881**	-0.781**	-0.478	-0.457
Silt	0.102	-0.164	0.310	0.246	-0.198	-0.026
Sand	-0.431	-0.435	0.911**	0.815**	0.581*	0.517
pH	0.955**	0.856**	-0.092	-0.061	-0.124	0.281
EC	0.913**	0.924**	-0.002	0.146	-0.006	0.443
ROC	0.133	0.225	0.933**	0.803**	0.800**	0.911**
TC	-0.187	-0.127	0.995**	0.859**	0.787**	0.782**
$CaCO_3$	0.885**	0.997**	-0.157	-0.060	0.076	0.422

*Significant at p=0.05; **Significant at p=0.01

4.5.3.5 Copper (Cu)

As shown in Table-4.46, the water soluble + exchangeable (Cu-F_1) fraction in sediments was significantly and positively correlated with pH, EC and $CaCO_3$ content of the sediments at p=0.01.

A significant and positive correlation was found between carbonate bound (Cu-F_2) fraction in sediment and pH, EC and $CaCO_3$ of the sediments at p=0.01.

The Organically bound (Cu-F_3) fraction in sediment was significantly and positively correlated with sand, readily carbon (ROC) and total carbon (TC) contents but negatively correlated with clay content of sediments at p=0.01.

The Fe-Mn oxide bound (Cu-F_4) fraction was significantly and positively correlated with sand content, ROC and TC of the sediments at p=0.01 but negatively correlated with clay content of sediments at p=0.01.

The residual (Cu-F_5) fraction was significantly and positively correlated with readily carbon (ROC) and total carbon (TC) content of the sediments at p=0.01 and with sand content at p=0.05, respectively.

The total Cu content was significantly and positively correlated with readily oxidizable carbon (ROC) and total carbon (TC) of the sediments at p=0.01.

4.5.3.6 Zinc (Zn)

The concentration of water soluble + exchangeable (Zn-F_1) fraction in sediments was significantly and positively correlated with pH, EC and $CaCO_3$ of the sediments at p=0.01.

A significant and positive correlation was found between carbonate bound (Zn-F_2) fraction in sediments and pH, EC and $CaCO_3$ of the sediments at p=0.01.

The Organically bound (Zn-F_3) fraction in sediments was significantly and positively correlated with sand, readily oxidizable carbon (ROC) and total carbon (TC) contents but negatively correlated with clay content of sediments at p=0.01, respectively.

The concentration of Fe-Mn oxide bound (Zn-F_4) fraction was significantly and positively correlated with pH, EC and $CaCO_3$ contents of the sediments at p=0.01.

The residual (Zn-F_5) fraction was significantly and positively correlated with pH, EC and $CaCO_3$ content of the sediments at p=0.01.

The total zinc content was significantly and positively correlated with pH, EC and $CaCO_3$ content of the sediments at p=0.01.

4.5.3.7 Cadmium (Cd)

Simple correlation coefficient values in Table-48 indicated that the concentration of water soluble + exchangeable (Cd-F_1) fraction in sediment was significantly and positively correlated with ROC and total carbon (TC) of the sediments at p=0.01 and 0.05, respectively.

Table 4.47 Relationship between physico-chemical properties of sediment and different chemical fractions of Zn in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Clay	0.391	0.478	-0.886**	0.353	0.167	0.243
Silt	0.042	-0.341	0.384	-0.306	0.119	-0.068
Sand	-0.447	-0.454	0.900**	-0.322	-0.215	-0.256
pH	0.909**	0.754**	-0.067	0.723**	0.869**	0.836**
EC	0.912**	0.845**	0.013	0.810**	0.838**	0.864**
ROC	0.172	0.211	0.933**	0.343	0.419	0.423
TC	-0.180	-0.133	0.984**	0.009	0.083	0.074
$CaCO_3$	0.933**	0.983**	-0.148	0.932**	0.847**	0.922**

*Significant at p=0.05; **Significant at p=0.01

Table 4.48 Relationship between physico-chemical properties of sediment and different chemical fractions of Cd in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Clay	-0.382	0.435	-0.932**	-0.239	-0.360	-0.488
Silt	0.123	0.284	0.349	0.867**	-0.080	0.150
Sand	0.397	-0.420	0.959**	0.063	0.421	0.510
pH	0.346	0.759**	-0.243	0.568*	-0.310	-0.030
EC	0.450	0.843**	-0.162	0.325	-0.190	0.062
ROC	0.843**	0.251	0.861**	0.157	0.373	0.643*
TC	0.653*	-0.091	0.981**	0.061	0.415	0.597*
$CaCO_3$	0.432	0.952**	-0.331	0.101	-0.141	0.049

*Significant at p=0.05; **Significant at p=0.01

A significant and positive correlation was found between carbonate bound (Cd-F_2) fraction in sediment and pH, EC and $CaCO_3$ of the sediments at p=0.01.

The Organically bound (Cd-F_3) fraction in sediment was significantly and positively correlated with sand, readily oxidizable carbon (ROC) and total carbon (TC) contents but negatively correlated with clay content of sediments at p=0.01, respectively.

The concentration of Fe-Mn oxide bound (Cd-F_4) fraction was significantly and positively correlated with silt content of the sediments at p=0.01 and with pH of sediments at p=0.05.

The residual (Cd-F_5) fraction in sediment did not show any significant correlation with any physico-chemical property of the sediments.

The total cadmium content was significantly and positively correlated with readily oxidizable carbon (ROC) and total carbon (TC) of the sediments at p=0.01.

4.5.3.8 Lead (Pb)

Simple correlation coefficient values in the Table-49 indicated that the concentration of water soluble + exchangeable (Pb-F_1) fraction in sediments was significantly and positively correlated with readily carbon (ROC) and total carbon (TC) of the sediments at p=0.01.

A significant and positive correlation was found between carbonate bound (Pb-F_2) fraction in sediment and pH, EC and $CaCO_3$ of the sediments at p=0.01. The concentration of Pb-F_2 fraction in the

Table 4.49 Relationship between physico-chemical properties of sediment and different chemical fractions of Pb in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Clay	-0.452	0.536*	-0.866**	-0.250	0.091	0.129
Silt	0.071	-0.166	0.399	0.862**	-0.457	-0.380
Sand	0.488	-0.560*	0.874**	0.075	0.006	-0.054
pH	0.130	0.865**	-0.008	0.635*	0.291	0.440
EC	0.236	0.911**	0.066	0.428	0.373	0.511
ROC	0.844**	0.068	0.950**	0.180	0.560*	0.560*
TC	0.731**	-0.286	0.971**	0.081	0.336	0.294
$CaCO_3$	0.251	0.987**	-0.097	0.156	0.596*	0.706**

*Significant at p=0.05; **Significant at p=0.01

Table 4.50 Relationship between physico-chemical properties of sediment and different chemical fractions of Ca in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Clay	0.290	0.377	0.276	0.403	0.382	0.374
Silt	-0.111	-0.367	-0.077	-0.414	-0.368	-0.346
Sand	-0.298	-0.335	-0.290	-0.353	-0.341	-0.337
pH	0.733**	0.685**	0.853**	0.649*	0.681**	0.699**
EC	0.694**	0.778**	0.884**	0.756**	0.781**	0.790**
ROC	0.374	0.343	0.392	0.319	0.337	0.345
TC	0.045	0.011	0.042	-0.010	0.003	0.009
$CaCO_3$	0.828**	0.938**	0.951**	0.932**	0.941**	0.944**

*Significant at p=0.05; **Significant at p=0.01

sediments was significantly and positively correlated with clay content but negatively correlated with sand content of sediments at p=0.05.

The Organically bound ($Pb-F_3$) fraction in sediment was significantly and positively correlated with sand, readily oxidizable carbon (ROC) and total carbon (TC) contents but negatively correlated with clay content of sediments at p=0.01, respectively.

The concentration of Fe-Mn oxide bound ($Pb-F_4$) fraction was significantly and positively correlated with silt content of the sediments at p=0.01 and with pH at p=0.05, respectively.

The residual ($Pb-F_5$) fraction was significantly and positively correlated with readily oxidizable carbon (ROC) and $CaCO_3$ content of the sediments at p=0.05.

The total Pb content was significantly and positively correlated with $CaCO_3$ content of the sediments at p=0.01 and readily oxidizable carbon (ROC) at p=0.05, respectively.

4.5.3.9 Calcium (Ca)

As shown in Table-4.50, the water soluble + exchangeable ($Ca-F_1$) fraction in sediments was significantly and positively correlated with pH, EC and $CaCO_3$ of the sediments at p=0.01.

A significant and positive correlation was noted between carbonate bound ($Ca-F_2$) fraction in sediments and pH, EC and $CaCO_3$ of the sediments at p=0.01.

The Organically bound ($Ca-F_3$) fraction in sediments was significantly and positively correlated with pH, EC and $CaCO_3$ of the sediments at p=0.01.

The Fe-Mn oxide bound (Ca-F_4) fraction in sediments was significantly and positively correlated with EC and $CaCO_3$ of the sediments at p=0.01 and with pH at p=0.05, respectively.

The residual (Ca-F_5) fraction in sediments was significantly and positively correlated with pH, EC and $CaCO_3$ of the sediments at p=0.01.

The total calcium content in sediment was significantly and positively correlated with pH, EC and $CaCO_3$ of the sediments at p=0.01.

4.5.3.10 Magnesium (Mg)

As shown in Table-4.51 the water soluble + exchangeable (Mg-F_1) fraction in sediments was significantly and positively correlated with readily oxidisable carbon (ROC) of the sediments at p=0.05.

A significant and positive correlation was noted between carbonate bound (Mg-F_2) fraction in sediments and pH, EC and $CaCO_3$ of the sediments at p=0.01 and with readily oxidisable carbon (ROC) of the sediments at p=0.05, respectively.

The Organically bound (Mg-F_3) fraction in sediments was significantly and positively correlated with E.C. and $CaCO_3$ of the sediments at p=0.01 and with pH of the sediments at p=0.05, respectively..

The Fe-Mn oxide bound (Mg-F_4) fraction in sediments was significantly and positively correlated with E.C., readily oxidisable carbon (ROC) and $CaCO_3$ content at p=0.01 and with pH of the sediments at p=0.05, respectively.

Table 4.51 Relationship between physico-chemical properties of sediment and different chemical fractions of Mg in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Clay	0.016	-0.091	0.513	0.009	-0.384	-0.163
Silt	-0.266	0.213	-0.498	-0.190	0.185	0.000
Sand	0.045	0.051	-0.455	0.035	0.385	0.182
pH	0.332	0.832**	0.605*	0.611*	0.398	0.545*
EC	0.325	0.855**	0.770*	0.725**	0.331	0.544*
ROC	0.600*	0.650*	0.154	0.663**	0.828**	0.763**
TC	0.378	0.351	-0.161	0.376	0.665**	0.519
$CaCO_3$	0.530	0.800**	0.937**	0.806**	0.354	0.615*

*Significant at p=0.05; **Significant at p=0.01

Table 4.52 Relationship between metal concentrations in waters with different chemical fractions of metal in sediments of different lakes

	W.S. and Exch.(F_1)	Carbonate bound (F_2)	Organically bound (F_3)	Fe-Mn oxide bound (F_4)	Residual (F_5)	Total content
Ca	0.755**	0.754**	0.852**	0.741**	0.760**	0.768**
Mg	0.395	0.795**	0.799**	0.784**	0.366	0.582*
Cr	0.988**	0.518	0.769**	0.614*	0.786**	0.896**
Mn	0.337	0.489	0.767**	0.692**	0.935**	0.953**
Fe	-0.342	-0.234	0.557*	-0.455	0.675**	0.621*
Ni	0.989**	0.531	0.139	0.635*	0.958**	0.958**
Cu	0.119	0.099	0.931**	0.805**	0.655*	0.785**
Zn	0.880**	0.803**	0.034	0.787**	0.866**	0.872**
Cd	0.733**	0.594*	0.255	-0.029	0.227	0.388
Pb	0.715**	0.570*	0.547*	0.041	0.919**	0.947**

*Significant at p=0.05; **Significant at p=0.01

The residual (Mg-F_5) fraction in sediments was significantly and positively correlated with readily oxidisable carbon (ROC) and total carbon (TC) of the sediments at p=0.01.

The total Magnesium content in sediments was significantly and positively correlated with readily oxidizable carbon (ROC) of the sediments at p=0.01 and with pH, E.C. and $CaCO_3$ at p=0.05, respectively.

4.5.4 Relationship between metal concentrations in water with their different chemical fractions in sediments

Simple correlation coefficients (r) computed between the concentrations of metal in waters and their different chemical fractions in the sediments of different lakes are presented in Table-4.52.

The concentration of Ca in the waters of different lakes was significantly and positively correlated with all chemical fractions of Ca as well as total calcium content in the sediments at p=0.01.

The concentration of Mg in the waters of different lakes was significantly and positively correlated with $CaCO_3$ bound (Mg-F_2), organically bound (Mg-F_3) and Fe-Mn oxide bound (Mg-F_4) fractions at p=0.01 and total magnesium content of the sediments at p=0.05, respectively.

The concentration of Cr in the waters of different lakes was significantly and positively correlated with water soluble + exchangeable (Cr-F_1), organically bound (Cr-F_3) and residual (Cr-F_5)

fractions and total Cr contents of the sediments at $p=0.01$ and with Fe-Mn oxide bound (Cr-F_4) at $p=0.05$, respectively.

The concentration of Mn in the waters of different lakes was significantly and positively correlated with organically bound (Mn-F_3), Fe-Mn oxide bound (Mn-F_4) and residual (Mn-F_5) fractions and total Mn contents of the sediments at $p=0.01$.

The concentration of Fe in the waters of different lakes was significantly and positively correlated with residual (Fe-F_5) fractions of the sediments at $p=0.01$ and with organically bound (Fe-F_3) and total iron contents at $p=0.05$, respectively.

The concentration of Ni in the waters of different lakes was significantly and positively correlated with water soluble + exchangeable (Ni-F_1) and total Ni content of the sediments at $p=0.01$ and with Fe-Mn oxide bound (Ni-F_4) and residual (Ni-F_5) fractions at $p=0.05$, respectively.

The concentration of Cu in the waters of different lakes was significantly and positively correlated with organically bound (Cu-F_3), Fe-Mn oxide bound (Cu-F_4) and residual (Cu-F_5) fractions and total Cu contents of the sediments at $p=0.01$.

The concentration of Zn in the waters of different lakes was significantly and positively correlated with water soluble + exchangeable (Zn-F_1), $CaCO_3$ bound (Zn-F_2), Fe-Mn oxide bound (Zn-F_4) and residual (Zn-F_5) fractions and total zinc contents of the sediments at $p=0.01$.

The concentration of Cd in the waters of different lakes was significantly and positively correlated with water soluble + exchangeable (Cd-F_1) at p=0.01 and $CaCO_3$ bound (Cd-F_2) fractions of the sediments at p=0.05, respectively.

The concentration of Pb in the waters of different lakes was significantly and positively correlated with water soluble + exchangeable (Pb-F_1) fraction and total Pb content at p=0.01 and $CaCO_3$ bound (Pb-F_2) organically bound (Pb-F_3) and residual (Pb-F_5) fractions of the sediments at p=0.05, respectively.

The relationships between the concentrations of different metals in waters and the intensity of different chemical fractions of respective metals indicate the state of dynamic equilibrium through which these chemicals fractions contribute directly or indirectly to ambient waters in the aquatic ecosystem.

Water soluble + exchangeable fraction of metals in sediments indicates the chemical fraction which is ready equilibrium with ambient water. A significant and positive correlation between concentrations of Ca, Cr, Ni, Zn, Cd and Pb with this chemical pool indicated the easy establishment of equilibrium in respect of these metals. The concentrations of Ca, Mg, Zn, Cd and Pb in waters showed significant and positive correlation with carbonate bound fractions of these metals in sediments. This kind of behaviour is attributed to affinity of these elements to form sparingly soluble carbonate salts which might release these metals under aquatic environment.

The concentrations of Ca, Mg, Cr, Mn, Fe, Cu and Pb in waters had significant and positive correlation with organically bound fraction of these metals. These metals are known to form organo-metallic complexes with organic matter which might release these metals depending upon their stability constants and prevailing physico-chemical conditions.

The concentrations of Ca, Mg, Cr, Mn, Ni, Cu and Zn in waters had significant and positive correlation with Fe-Mn oxide bound fraction. Iron and Mn-oxide are known sinks of metals especially heavy metals in aquatic system. These oxides are amphoteric in nature and develop charges depending upon the prevailing pH of the system. Since the pH values of waters were alkaline, the oxides would have negative charges and could be expected to hold cations partly in non-specifically bound form.

The concentrations of all cations except Mg and Cd in waters had significant and positive correlation with residual fraction of these metals. The residual fraction is likely to hold these metals either as a structural constituent of their lattice structure or as discrete precipitate of insoluble sulphides etc. Under anaerobic conditions, some part of residual fraction is likely to release metals.

The concentrations of all metals except Cd showed a significant and positive correlation with the total content of respective metals in sediments. This kind of behaviour is not common in agricultural soils but could be expected in aquatic ecosystem where only anoxic environment prevails.

SUMMARY

Summary

The present investigation was undertaken to analyse some water quality parameters of waters of seven natural lakes of Nainital, Uttaranchal and to study the heavy metal loads in lake sediments. During 2003-05, water and sediment samples were collected in nine and two seasons, respectively. Different physico-chemical properties and concentration of cations, anions and heavy metals in waters were analyzed. Sediment samples were analysed for physico-chemical properties and different chemical fractions of metals. Relationships between physico-chemical properties of water with concentration of cations, anions and heavy metals in waters were computed. Relationships between different chemical fractions of metals with physico-chemical properties of sediment and with their relative concentrations in water were also established.

The results of the present investigation are summarized below:

1. The pH, electrical conductivity, dissolved oxygen, biological oxygen demand, chemical oxygen demand and alkalinity/bicarbonate in waters of different lakes varied from 7.69-8.63, 0.07-0.63 mS cm^{-1}, 3.12-9.66 mg L^{-1}, 0.43-2.96 mg L^{-1}, 65.1-373.1 mg L^{-1} and 53.1-296.4 mg L^{-1}, respectively. Carbonate content were not detectable in water samples. Among lakes, Nainital and Punatal had the maximum and minimum contents of these physico-chemical parameters except for dissolved oxygen, respectively. The maximum

and minimum dissolved oxygen values were found in Punatal and Nainital, respectively.

Higher pH, electrical conductivity, biological oxygen demand, chemical oxygen demand and alkalinity in waters of different lakes were found during summers of 2003-04 and 2004-05. Whereas, the maximum content of dissolved oxygen was found during autumns in both years.

2. The concentrations of NH_4^+-N, K^+, Na^+, Ca^{2+}, Mg^{2+} and hardness in waters of different lakes varied from 0.14-2.07, 2.01-8.81, 10.04-44.03, 6.56-52.56, 4.33-11.08 and 38.6-172.8 mg L^{-1}, respectively. Among lakes, Nainital had the maximum content of these cations and hardness while the minimum concentrations of NH_4^+-N, Ca^{2+}, Mg^{2+} and hardness were found in Punatal. The minimum concentrations of K^+ and Na^+ were found in Ramtal.

Higher contents of NH_4^+-N, K^+, Na^+, Ca^{2+}, Mg^{2+} and hardness in waters of different lakes were found during summers of 2003-04 and 2004-05. The lowest contents of these cations and hardness were recorded during autumn seasons of both the years.

3. The concentrations of NO_3^--N, PO_4^{3-}-P, SO_4^{2-}-S and Cl^- in waters of different lakes varied from 0.40-7.98, 0.05-1.08, 1.50-48.35 and 5.05-29.85 mg L^{-1}, respectively. Among lakes, Nainital and Punatal had the maximum and minimum concentration of these anions, respectively.

Higher contents of NO_3^--N, PO_4^{3-}-P, SO_4^{2-}-S and Cl^- in waters of different lakes were found during summers of both years. The lowest contents of these anions were found during autumn seasons of both the years.

4. The sodium adsorption ratio and residual sodium carbonate in waters of different lakes varied from 0.58-1.70 and 0.07-1.47 me L^{-1}, respectively. Among lakes, Nainital and Sitatal had the maximum and minimum values of SAR and RSC, respectively.

5. Total bacterial population and most probable number in waters of different lakes varied from 705-2758 mL^{-1} and 4-984 per 100 ml, respectively. Among lakes, Nainital and Bhimtal had the maximum and minimum total bacterial population and most probable number, respectively.

   Higher population of bacteria and MPN in waters of different lakes was found during summers as compared to winters in both the years.

6. The concentrations of Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb in waters of different lakes varied from 0.29-2.39, 10.3-38.3, 431-1407, 1.0-6.6, 5.3-12.1, 12.6-166.3, 0.7-2.7 and 3.9-27.1 µg L^{-1}, respectively. Among lakes, Naukuchiatal had the maximum concentrations of Cr, Mn, Fe, and Cu whereas, the maximum concentrations of Ni, Zn, Cd and Pb were found in Nainital. The minimum concentration of Cr was found in Hanumantal. The minimum concentrations of Mn and Cd were found in Punatal. Bhimtal contained the minimum

concentrations of Fe and Ni. The minimum concentration of Cu was found in Sitatal. The minimum concentrations of Zn and Pb were found in Ramtal.

Higher concentrations of Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb in waters of different lakes were found during summers of 2003-04 and 2004-05. The lowest content of these heavy metals was found during autumns of both years.

7. Clay, silt and sand contents in sediments of different lakes varied from 9.0-24.7, 2.0-5.7 and 73.3-87.7 %, respectively. The highest clay, silt and sand contents were found in Nainital, Bhimtal and Naukuchiatal, respectively.

8. The sediments of all lakes were alkaline in pH (7.81-8.99). The electrical conductivity, readily oxidized carbon, total carbon and $CaCO_3$ equivalent in sediments of different lakes varied from 0.093-0.232 mS m^{-1}, 0.18-0.72 %, 0.55-2.38 % and 2.64-37.74 %, respectively. The maximum values of pH, electrical conductivity and $CaCO_3$ equivalent of sediments were found in Nainital whereas, the maximum values of readily oxidized carbon and total carbon were found in Naukuchiatal.

9. The water soluble + exchangeable (Cr-F_1), $CaCO_3$ bound (Cr-F_2), organically bound (Cr-F_3), iron and Mn oxide bound (Cr-F_4) and residual (Cr-F_5) fractions and total Cr contents in sediments of different lakes varied from 0.27-0.80, 0.44-1.06, 0.31-0.84, 0.83-2.69, 12.4-17.4 and 14.3-21.5 μg g^{-1}, respectively. The maximum

contents of Cr-F_1, Cr-F_2, and Cr-F_5 fractions and total Cr were found in Nainital whereas, the maximum concentrations of Cr-F_3 and Cr-F_4 fractions were found in Naukuchiatal and Bhimtal, respectively.

10. The water soluble + exchangeable (Mn-F_1), $CaCO_3$ bound (Mn-F_2), organically bound (Mn-F_3), iron and Mn oxide bound (Mn-F_4) and residual (Mn-F_5) fractions and total Mn contents in sediments of different lakes varied from 1.1-2.8, 20.4-73.1, 2.1-11.1, 11.4-28.7, 50.5-115.3 and 90.1-197.5 μg g^{-1}, respectively. The maximum content of Mn-F_1, Mn-F_2, and Mn-F_3 fractions and total Mn were found in Nainital whereas, the maximum concentration of Mn-F_3 and Mn-F_5 fractions was found in Naukuchiatal.

11. The water soluble + exchangeable (Fe-F_1), $CaCO_3$ bound (Fe-F_2), organically bound (Fe-F_3), iron and Mn oxide bound (Fe-F_4) and residual (Fe-F_5) fractions and total Fe contents in sediments of different lakes varied from 1.6-3.2, 6.5-125.6, 21.3-57.9, 318.9-588.7, 4701-6003 and 5265-6428 μg g^{-1}, respectively. The maximum content of Fe-F_1, Fe-F_2, and Fe-F_5 fractions and total Fe were found in Nainital whereas, the maximum concentrations of Fe-F_3 and Fe-F_4 fractions were found in Naukuchiatal and Bhimtal, respectively.

12. The water soluble + exchangeable (Ni-F_1), $CaCO_3$ bound (Ni-F_2), organically bound (Ni-F_3), iron and Mn oxide bound (Ni-F_4) and residual (Ni-F_5) fractions and total Ni contents in sediments of different lakes varied from 1.01-1.98, 3.20-6.80, 2.01-5.37, 1.35-

3.86, 6.6-28.0 and 17.7-45.9 μg g^{-1}, respectively. The maximum content of Ni-F_1, Ni-F_2, Ni-F_4 and Ni-F_5 fractions and total Ni were found in Nainital whereas, the maximum concentration of Ni-F_3 and fractions was found in Bhimtal.

13. The water soluble + exchangeable (Cu-F_1), $CaCO_3$ bound (Cu-F_2), organically bound (Cu-F_3), iron and Mn oxide bound (Cu-F_4) and residual (Cu-F_5) fractions and total Cu contents in sediments of different lakes varied from 0.31-0.71, 1.07-8.80, 0.41-2.6, 2.69-11.69, 4.25-18.53 and 12.5-32.0 μg g^{-1}, respectively. The maximum content of Cu-F_1 and Cu-F_2 fractions were found in Nainital whereas, the maximum concentrations of Cu-F_3, Cu-F_4 and Cu-F_5 fractions and total Cu were found in Naukuchiatal.

14. The water soluble + exchangeable (Zn-F_1), $CaCO_3$ bound (Zn-F_2), organically bound (Zn-F_3), iron and Mn oxide bound (Zn-F_4) and residual (Zn-F_5) fractions and total Zn contents in sediments of different lakes varied from 1.54-2.25, 2.52-14.04, 1.27-8.66, 2.5-41.82, 27.71-87.77 and 40.0-149.2 μg g^{-1}, respectively. The maximum content of Zn-F_1, Zn-F_2, Zn-F_4 and Zn-F_5 fractions and total Zn were found in Nainital whereas, the maximum concentration of Zn-F_3 fraction was found in Naukuchiatal.

15. The water soluble + exchangeable (Cd-F_1), $CaCO_3$ bound (Cd-F_2), organically bound (Cd-F_3), iron and Mn oxide bound (Cd-F_4) and residual (Cd-F_5) fractions and total Cd contents in sediments of different lakes varied from 0.53-0.97, 1.61-2.47, 0.33-0.87, 0.25-

0.65, 8.1-10.8 and 11.1-14.6 μg g^{-1}, respectively. The maximum content of Cd-F_1 and Cd-F_2 fractions were found in Nainital whereas, the maximum concentrations of Cd-F_3 and total Cd were found in Naukuchiatal. The maximum content Cd-F_4 and Cd-F_5 fractions were found in Bhimtal and Sitatal, respectively.

16. The water soluble + exchangeable (Pb-F_1), $CaCO_3$ bound (Pb-F_2), organically bound (Pb-F_3), iron and Mn oxide bound (Pb-F_4) and residual (Pb-F_5) fractions and total Pb contents in sediments of different lakes varied from 5.09-6.54, 4.65-17.40, 0.63-2.71, 4.39-8.39, 69.4-137.1 and 88.9-167.4 μg g^{-1}, respectively. The maximum content of Pb-F_1 and Pb-F_3 fractions were found in Naukuchiatal whereas, the maximum concentrations of Pb-F_2 and Pb-F_5 fractions and total Pb were found in Nainital. The maximum content of Pb-F_4 was found in Bhimtal.

17. The water soluble + exchangeable (Ca-F_1), $CaCO_3$ bound (Ca-F_2), organically bound (Ca-F_3), iron and Mn oxide bound (Ca-F_4) and residual (Ca-F_5) fractions and total Ca contents in sediments of different lakes varied from 62-424, 24-6818, 10-1534, 9-862, 65-11140 and 247-20441 μg g^{-1}, respectively. The maximum content of Ca-F_1, Ca-F_2, Ca-F_3, Ca-F_4 and Ca-F_5 fractions and total Ca were found in Nainital.

18. The water soluble + exchangeable (Mg-F_1), $CaCO_3$ bound (Mg-F_2), organically bound (Mg-F_3), iron and Mn oxide bound (Mg-F_4) and residual (Mg-F_5) fractions and total Mg contents in sediments of

different lakes varied from 58-164, 49-212, 27-2137, 41-279, 783-5377 and 1410-8169 µg g^{-1}, respectively. The maximum content of Mg-F_1, Mg-F_2, Mg-F_3, Mg-F_4 and Mg-F_5 fractions and total Mg were found in Nainital.

19. The concentrations of all cations and anions in waters were positively correlated with pH, electrical conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD) and alkalinity of waters but negatively correlated with dissolved oxygen (DO).

20. The concentrations of Cr, Mn, Ni, Cu, Zn, Cd and Pb were positively correlated with pH, electrical conductivity (EC), biological oxygen demand (BOD), Chemical oxygen demand (COD) and alkalinity of waters but negatively correlated with dissolved oxygen (DO).

21. Carbonate bound-Pb fraction showed a positive correlation but organically bound-Cr, Mn, Fe, Cu, Zn, Cd and Pb; Fe-Mn oxide bound-Cu, residual-Mn and Fe fractions and total-Fe in sediments showed a negative correlation with clay content in lake sediments from lakes.

22. Iron and Mn-oxides bound-Cr, Fe, Cd and Pb fractions showed a positive with silt content in sediments from lakes but residual-Ni had a negative correlation.

23. Organically bound-Cr, Mn, Fe, Cu, Zn, Cd and Pb; Fe-Mn oxide bound-Cu, residual-Mn, Fe, and Cu fractions and total iron content had a positive correlation with sand content of sediments from

lakes but water soluble + exchangeable-Mn and carbonate bound-Pb fractions in sediments had a negative correlation with this property.

24. The carbonate bound-fractions of all metals, water soluble + exchangeable-Mn, Fe, Ni, Cu, Zn and Ca; organically bound-Ca and Mg; reducible-fraction of all metals except Cu; residual-Zn and Ca and total-Ni, Zn, Mg and Ca had a positive correlation while residual-Fe had a negative correlation with pH of the lake sediments.

25. Carbonate bound fraction of all metals; water soluble-Mn, Fe, Ni, Cu, Zn and Ca; organically bound-Ca and Mg; reducible-Mn, Ni, Zn, Ca and Mg; residual-Ni, Zn and Ca and total-Ni, Zn, Ca and Mg had a positive correlation with electrical conductivity of sediments for different lakes.

26. Water soluble + exchangeable-Cr, Cd and Pb; organically bound-fraction of all metals except Ni, Ca and Mg; reducible-Cu and Mg; residual-Cr, Mn, Fe, Cu, Pb and Mg fractions and total content of all metals except Ni, Zn and Ca were positively correlated with readily oxidisable carbon.

27. Water soluble + exchangeable-Cr, Cd and Pb; organically bound-Mn, Fe, Cu, Zn, Cd and Pb; reducible-Cu; residual-Mn, Fe, Cu and Mg fractions and total-Cr, Mn, Fe, Cu and Cd were positively correlated with total carbon.

28. Carbonate bound-fraction of all metals; water soluble + exchangeable-Mn, Fe, Ni, Cu, Zn and Ca; organically bound-Ca and Mg; reducible-Mn, Ni, Zn, Ca and Mg; residual-Ni, Zn, Pb and Ca and total-Ni, Zn, Pb, Ca and Mg had a positive correlation while residual Fe had a negative correlation with $CaCO_3$ equivalent % in sediments of different lakes.
29. The concentrations of Ca, Cr, Ni, Zn, Cd and Pb in waters were positively related with water soluble + exchangeable fraction of these metals in lake sediments.
30. The concentrations of Ca, Mg, Zn, Cd and Pb in waters were positively correlated with carbonate bound fraction of these metals in lake sediments.
31. The concentrations of all metals except Ni, Zn and Cd in waters were positively correlated with organically bound fraction of these metals in lake sediments.
32. The concentrations of Ca, Mg, Cr, Mn, Ni, Cu and Zn in waters were positively correlated with reducible fraction of these metals in lake sediments.
33. The concentrations of all metals except Mg and Cd in waters were positively correlated with residual fraction of these metals in lake sediments.
34. The concentrations of all metals except Cd in waters were positively correlated with residual fraction of these metals in lake sediments.

Thus, water quality of the lakes of Nainital district was safe. In relative terms, waters of Nainital were more polluted whereas, waters of Punatal were having the minimum pollution. In general, an ion rich alkaline environment of these lakes makes them prone to the problem of eutrophication. A regular cleaning of these lakes for hydrophytes would be essential for their maintenance. Anthropogenic interferences due to tourist inflow during summer months raise the level of organic loads in more popular lakes like Nainital, Bhimtal and Naukuchiatal. Regulatory measures must be enforced to refrain disposal of wastes in these lakes.

The concentrations of all metals except Cd in waters from different lakes are closely related to the levels of these metals in lake sediments.

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APPENDIX

Appendix I

Chemical fractions of metals as % of total metal content in sediments

Fractions	Bhimtal	Naukuchiatal	Punatal	Sitatal	Ramtal	Hanumantal	Nanital	Average
Cr-F_1	4.02	3.79	3.58	1.72	1.92	1.89	3.75	2.95
Cr-F_2	4.04	2.58	2.95	3.37	3.13	3.15	4.84	3.44
Cr-F_3	4.11	4.22	1.66	1.89	2.09	2.13	3.16	2.75
Cr-F_4	12.85	6.19	7.33	6.44	5.80	6.42	6.87	7.42
Cr-F_5	75.24	83.71	84.19	85.29	87.00	86.32	81.43	83.31
Mn-F_1	1.56	0.65	1.65	1.52	1.54	1.43	1.43	1.40
Mn-F_2	32.18	12.28	23.78	26.15	32.25	25.79	35.58	26.86
Mn-F_3	4.64	6.55	5.02	4.35	2.97	4.54	2.78	4.41
Mn-F_4	15.30	9.03	16.19	12.04	11.94	12.81	14.31	13.09
Mn-F_5	52.56	66.86	53.88	55.61	57.06	52.68	45.98	54.95
Fe-F_1	0.05	0.03	0.03	0.03	0.03	0.03	0.06	0.04
Fe-F_2	0.47	0.10	0.17	0.30	0.33	0.32	2.33	0.58
Fe-F_3	0.67	0.91	0.60	0.49	0.41	0.52	0.66	0.61
Fe-F_4	10.66	5.56	7.25	7.43	6.53	5.99	7.59	7.29
Fe-F_5	88.18	93.42	91.97	91.76	92.71	93.15	89.36	91.51
Ni-F_1	4.69	4.52	4.48	5.22	5.22	4.86	4.69	4.81
Ni-F_2	29.64	13.94	14.98	17.21	17.53	17.60	15.21	18.01
Ni-F_3	24.26	22.39	22.28	21.90	25.55	24.09	12.52	21.86
Ni-F_4	11.49	8.18	8.02	10.49	9.79	8.37	7.28	9.09
Ni-F_5	33.98	56.55	56.85	51.09	49.69	52.34	63.66	52.02
Cu-F_1	2.78	1.04	2.42	2.82	2.70	2.43	2.13	2.33
Cu-F_2	20.21	3.59	8.77	15.87	18.13	14.67	29.59	15.84
Cu-F_3	5.11	8.53	3.49	3.21	2.73	3.30	2.78	4.17
Cu-F_4	38.81	38.67	25.16	41.87	44.54	42.74	24.28	36.58
Cu-F_5	25.32	55.18	60.40	34.16	30.86	34.14	41.70	40.25
Zn-F_1	2.25	2.78	3.06	3.53	3.27	2.99	1.52	2.77
Zn-F_2	5.52	4.52	6.01	8.81	8.41	7.48	9.74	7.21
Zn-F_3	5.19	15.13	3.74	3.12	2.42	2.92	2.95	5.07
Zn-F_4	11.09	8.92	9.17	9.31	6.80	15.45	28.48	12.75
Zn-F_5	75.91	73.91	78.11	74.92	78.24	71.27	57.85	72.89
Cd-F_1	5.67	5.90	4.73	4.33	5.33	4.92	6.33	5.32
Cd-F_2	14.79	11.95	13.22	12.27	16.26	15.23	18.25	14.57
Cd-F_3	4.00	6.17	2.96	2.76	3.25	3.15	2.78	3.58
Cd-F_4	4.98	2.23	2.90	2.69	2.44	2.18	2.56	2.86
Cd-F_5	69.22	74.23	75.45	78.10	72.86	74.61	72.15	73.80
Pb-F_1	5.85	5.31	4.78	5.89	6.35	5.28	3.74	5.32
Pb-F_2	10.75	3.96	5.83	8.70	9.51	8.86	10.27	8.27
Pb-F_3	1.70	2.24	0.80	0.83	0.84	0.91	0.94	1.18
Pb-F_4	8.39	3.86	4.06	4.81	5.26	4.66	3.01	4.87
Pb-F_5	72.92	85.42	84.61	79.63	78.10	80.29	82.05	80.43
Ca-F_1	13.47	36.87	48.99	32.01	29.36	24.65	2.02	26.77
Ca-F_2	18.86	21.90	18.41	11.01	9.93	9.34	32.77	17.46
Ca-F_3	39.51	10.66	8.79	4.26	5.18	3.97	7.56	11.42
Ca-F_4	0.63	5.15	6.29	9.41	10.38	8.54	4.23	6.37
Ca-F_5	30.91	26.26	18.63	42.94	45.12	53.85	53.55	38.75
Mg-F_1	1.87	2.19	3.17	4.91	4.57	4.15	2.01	3.27
Mg-F_2	3.50	1.94	1.39	3.78	3.50	3.99	2.56	2.95
Mg-F_3	1.79	0.83	0.88	30.93	30.67	33.25	26.50	17.84
Mg-F_4	2.26	2.55	1.69	3.86	3.03	4.58	3.43	3.06
Mg-F_5	90.64	92.53	92.95	57.19	58.70	53.71	65.89	73.09

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ABSTRACT

The present investigation was undertaken to analyse some water quality parameters and the heavy metals load in waters of seven natural lakes viz., Bhimtal, Naukuchiatal, Punatal, Sitatal, Ramtal, Hanumantal and Nainital, Uttaranchal and also the heavy metals load in lake sediments during 2003-04 and 2004-05. The water samples were collected during summer, autumn, winter and spring seasons while sediment samples were collected during summers. The water and sediment samples were analysed for various parameters. The values of pH were found to vary from neutral to slightly alkaline well within permissible limits. The values of EC varied from 0.08-0.62 mS cm^{-1} and that of DO, BOD, COD and alkalinity varied from 3.12 to 9.66, 0.43-2.96, 65.1-373.1 and 53.1-296.4 mg L^{-1}, respectively. The concentrations of NH_4^+-N, K^+, Na^+, Ca^{2+}, Mg^{2+}, NO_3^--N, PO_4^{3-}-P, SO_4^{2-}-S and Cl^- in waters of different lakes varied from 0.14-2.07, 2.01-8.81, 10.04-44.03, 6.56-52.56, 4.33-11.08, 0.40-7.98, 0.05-1.08, 1.50-48.35, 5.05-29.85, 38.6-172.8 mg L^{-1}, respectively. The hardness, SAR and RSC in waters of different lakes varied from 38.6-172.8 mg L^{-1}, 0.58-1.70 and 0.07-1.47 me L^{-1}, respectively. Total bacterial population and most probable number in waters of different lakes varied from 705-2758 ml^{-1} and 4-984 per 100 ml, respectively. The concentrations of Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb in waters of different lakes varied from 0.29-2.39, 10.3-38.3, 431-1407, 1.0-6.6, 5.3-12.1, 12.6-166.3, 0.7-2.7 and 3.9-27.1 µg L^{-1}, respectively. The concentrations of metals in sediments were higher than in waters from different lakes. The concentrations of all metals except Cd in waters from different lakes are closely related to the levels of these metals in lake sediments. Among all lakes studied, Nainital was in relative terms found to be the most polluted while Punatal suffered minimum pollution. The water quality of these lakes declined during summer season when maximum tourist activities occurred. For conservation of these lakes as glory and pristine beauty of this region, a regular monitoring and effective measurements is urgently warranted.

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