TEMPORAL AND SPATIAL ASSESSMENT OF WATER QUALITY OF MAJOR RIVERS OF UTTARAKHAND: IMPACT OF SEWAGE AND INDUSTRIAL EFFLUENT

By

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(Ankur Kansal)

DECLARATION

“I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Ankur Kansal

Date:

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on **"Temporal and Spatial Assessment of Water Quality of Major River of Uttarakhand: Impact of Sewage and Industrial Effluent"** by **Ankur Kansal** in partial completion of the requirements for the award of the Degree of Doctor of Philosophy (Science) is an original work carried out by him under our joint supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

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EXECUTIVE SUMMARY

In the present study surface water quality of major rivers and lake of Uttarakhand is carried out. Impact of industrial waste water and domestic sewage is also envisaged. For the purpose of sampling all rivers and lakes of the study area were grouped into four sectors I) River Ganga System having 15 sampling/monitoring stations, II) River Yamuna System having 05 monitoring/sampling stations (i and ii are of Garhwal Region), III) Ram Ganga River System having 08 sampling/monitoring station and IV) two monitoring stations at Naini Lake (III and IV are of Kumaon region) making a total of 30 sites. Samples were collected during Winter (January 2010), spring, (April 2010), Monsoon/ Summer (July 2010) and Autumn (October 2010). Integrated grab samples were collected in high-grade plastic bottles of 2 Liter capacity in triplicate and mixed to get a composite sample. All the sample bottles were stored in ice box till brought to laboratory for analysis. On site analysis of Dissolved oxygen was done gravimetrically; pH, Electrical Conductivity, was measured by Eventech Cybernetics Model meters. Water samples were preserved at pH < 2 in separate 300 ml plastic bottle by adding concentrated HNO_3 for heavy metal analysis.

Samples for Pb, Cu, Fe, Zn were analyzed by Atomic Absorption Spectrophotometer (Perkin Elmer A Analyst 300). Due to limited availability of lamps only aforesaid four heavy metals were analyzed. A.R. grade chemicals were used for analysis as per the standard methods. Observed values for various parameters were statically analyzed by using correlation study, t-test, ANOVA on MS Excel software.

Temperature varied from 13.0^0C to 24.0^0C in both river Ganga System and river Yamuna System with mean value of 17.4^0C and 17.8^0C respectively. However it varied from 19^0C -28^0C with mean value 21^0C and 17^0C -21^0C with mean value 20 ^{0}C in Kumaon rivers and Naini Lake respectively. Lower temperature was

found at higher altitudes and higher temperature was found in the water bodies flowing in plains. Values of pH varied from 7.4 to 8.8 with mean value 8.03 in Ganga river system, 7.8 to 8.9 with mean value of 8.05 in Yamuna river system, 6.6 to 9.1 with mean value of 7.4 in Kumaon rivers and 6.5 to 8.2 with mean value of 7.4 in Naini lake. Higher variation of pH was found in Kumaon rivers. Change in pH values results in change in ionic behavior of the water body and thus results in chelation of the heavy metals along with organic components present in water body. This ultimately results in deterioration of water quality. Higher temperature results in escaping of dissolved oxygen and other gases which reduce the Dissolved oxygen in water bodies. Most of the wastewater discharging industries are situated in Kumaon region and dispose industrial effluent into rivers and hence the rivers of Kumaon region showed higher fluctuations in pH values.

Concentration of DO varied from 3.6 mgl^{-1} to 10.20 mgl^{-1} with mean value of 6.95 mg^{-1} in river Ganga, 3.20 mgl^{-1} to 8.90 mgl^{-1} with mean value of 6.9 mgl^{-1} in river Yamuna, not traceable to 9.6 mgl^{-1} with mean value of 3.14 mg^{-1} in Kumaon rivers and 4.0 $mgl^{-1}$to 8.60 mgl^{-1} with mean value of 6.9 mgl^{-1} in Naini lake. However, very low concentration of DO was observed in river of Kumaon regions which were even zero at many points. Low values of DO indicate poor self sustain system of water bodies which results in increased BOD. Out of 120 samples studied, DO was found less than 3 in 19 samples (water is not suitable for fishing bathing, industrial cooling), in 07 samples it was found between 3 and 4 (water is considered suitable for industrial cooling, aesthetic and recreation), between 4 and 5 in 10 samples (suitable for bathing, commercial fishing) and more than 5 in 84 samples (indicator of pure water).

BOD in river Ganga system varied from 2.1 mgl^{-1} to 15.6 mg^{-1} with mean value of 6.98 mg^{-1}. It varied from 2.2 mgl^{-1} to 12.6 mg^{-1} with mean value of 6.44 mg^{-1} in River Yamuna System. BOD in Kumaon Rivers varied from 4.80 mgl^{-1} to 140 mgl^{-1} with mean value of 52 mgl^{-1}. Naini lake represented stable and lower BOD. Out of 120 observations in the present study none of the sample was within the WHO prescribed limit 1.3 mgl^{-1}. This indicates higher load of organic pollutants in the river bodies due to increased urbanization and industrialization. DO and BOD in all the water bodies shows negative correlation means higher the BOD lower DO and vice versa.

Higher values of TDS, TSS and EC were observed in pre-monsoon season than in winter. All three parameters showed higher positive correlation with each other and negative correlation with Dissolved Oxygen. TDS, TSS and EC showed higher concentrations in Kumaon Rivers. During the entire study period mean temporal concentration of TDS varied from 169.8 mgl^{-1} to 268.27 mgl^{-1}in river Ganga system; 155.4 mgl^{-1} to 217.6 mgl^{-1}in river Yamuna System; 577.25 mgl^{-1} to 951.25 mgl^{-1} in Kumaon rivers and 383.5 mgl^{-1} to 413 mgl^{-1} in Naini lake. Mean temporal concentration of TSS varied from 118.13 mgl^{-1} to 153.2 mgl^{-1}; 79.8 mgl^{-1} to146.4 mgl^{-1}; 343 mgl^{-1} to 513 mgl^{-1} and 272 mgl^{-1} to 385 mgl^{-1} in river Ganga system, river Yamuna System, Kumaon river and Naini lake, respectively. There was a significant difference in minimum values of TDS and TSS. However maximum values did not show many variations. Almost all the samples of Kumaon rivers and a few of river Ganga and Yamuna were fund exceeded by the desirable limit for TDS. Mean temporal concentration of EC varied from 221.73 $\mu mhocm^{-1}$ to 264.93 $\mu mhocm^{-1}$; 210 $\mu mhocm^{-1}$ to 243.6 $\mu mhocm^{-1}$; 401 $\mu mhocm^{-1}$ to 509.6 $\mu mhocm^{-1}$ and 500 $\mu mhocm^{-1}$ to 573 $\mu mhocm^{-1}$ in river Ganga system, river Yamuna System, Kumaon rivers and Naini lake, respectively. Total Hardness was found always higher from Total Alkalinity. Total Hardness is due to the carbonates, bicarbonates, and hydroxide ions in water. However, alkalinity is due to abundance of hydroxide ion. Hence Total Hardness is higher than Total Alkalinity. Higher values of both parameters were observed in pre-monsoon season than in winter season in river Ganga system. During the entire study period mean temporal values of Total Hardness was ranged from 177.73 mgl^{-1} to 201.33 mgl^{-1}; and 176 mgl^{-1} to 255.20 mgl^{-1} in river Ganga System and river Yamuna system respectively. Mean temporal concentration varied from 177.88 mgl^{-1} to 245.5 mgl^{-1} 180 mgl^{-1} to 341 mgl^{-1} in Kumaon rivers and Naini Lake. Total Hardness exceeded desirable limits of 300 mgl^{-1} in most of the samples of Kumaon rivers. Mean temporal values of Total Alkalinity varied from

94 mgl^{-1} to 102.13 mgl^{-1}; 108 mgl^{-1} to 125 mgl^{-1}; 178.5 mgl^{-1} to 191.5 $mgl^{-1}$and 189 mgl^{-1} to 216 mgl^{-1} at river Ganga system, river Yamuna, Kumaon rivers and Naini lake, respectively. Higher values of Total Alkalinity were also observed in the Kumaon rivers. Total Alkalinity and Total Hardness both showed higher positive correlation in all water bodies. Total Hardness also shows positive correlation with chloride in all river bodies except in Naini lake.

Average temporal values of Sodium were always found lower than Potassium in all water bodies. During the entire study average temporal values of Sodium was ranged from 9.81 to 11.99 mgl^{-1} and Potassium ranged from 49.19 mgl^{-1} to 60.96 mgl^{-1} in river Ganga system. River Yamuna had relatively lower values of Sodium and Potassium in different seasons and temporal mean values ranged from 7.46 mgl^{-1} to 8.69 mgl^{-1} and 35.51 mgl^{-1} to 42.12 mgl^{-1} respectively. Kumaon rivers showed mean temporal concentration of Na and K as 9.36 mgl^{-1} to 10.68 mgl^{-1} and 22.24 mgl^{-1} to 22.67 mgl^{-1} respectively. Sodium varied from 2.66 mgl^{-1} to 3.25 mgl^{-1} and Potassium varied from 11.10 mgl^{-1} to 12.91 mgl^{-1} in Naini lake. Sodium and Potassium showed positive correlation with all other studied parameters in the present study except DO in all river bodies except in Naini lake. Potassium showed higher positive correlation with BOD, TDS Cl and it interestingly showed negative correlation with Na in Naini lake which may be due to ecology of the lake having close water circuit and different water strata than rivers. Sodium had higher positive correlation with Phosphate and Chloride and higher negative correlation with pH, TDS and BOD.

Mean temporal values of Chloride varied from 8.87 mgl^{-1} to 11.93 mgl^{-1}, 6.80 mgl^{-1} to 10.80 mgl^{-1}, 5.25 mgl^{-1} to 7.13 mgl^{-1} and 12.50 mgl^{-1} to 18.50 mgl^{-1} in river Ganga System, river Yamuna System, Kumaon rivers and lake Naini respectively during the entire study period.

Higher concentration of Phosphate results in nutrient enrichment in the water bodies and create problem of algal blooms. Phosphate showed higher positive correlation with Sodium, Potassium, Electrical Conductivity, Total Dissolved Solids and Total Suspended Solids. It is inferred that concentration of phosphate move parallel with the above constituents and phosphate showed opposite behavior with Dissolved Oxygen. Higher DO results in aerobic digestion by microorganisms in water bodies and help in dissociation of Phosphate thus lower the concentration observed. Mean temporal values of Phosphate in river Ganga System during all sampling periods ranged from 107.66 μgl^{-1} to 197.22 μgl^{-1}, 64.53 μgl^{-1} to 124.66 μgl^{-1}, 56.51 μgl^{-1} to 207.05 μgl^{-1} and 90.89 μgl^{-1} to 172.63 μgl^{-1} in river Ganga System, river Yamuna System, Kumaon rivers and lake Naini respectively. Phosphate concentration was found always higher in pre-monsoon season than in winter.

Mean value of (i) Pb was 0.24 mg/l, 0.14 mg/l, 3.44 mg/l and 0.26 mg/l; (ii) Cu was 0.87 mg/l, 0.42 mg/l, 4.99 mg/l and 0.20 mg/l; (iii) Fe was 0.27 mg/l, 0.20 mg/l, 1.01 mg/l and 0.70 mg/l; (iv)Zn was 0.1 mg/l, 0.04 mg/l, 0.08 mg/l and 0.05 mg/l found in river Ganga system, river Yamuna System, River Ram ganga System and in Lake Naini respectively. There is not any significant temporal variation of all studied heavy metals was found in the present study. However, concentration varied spatially with higher concentration in Kumaon region. In all studied metals, where the concentration was found not detectable were belongs to Garhwal region in mostly river originated areas. Lead detected in 96 samples out of 120 samples with mean value 0.22 mg/l and 2.80 mg/l in Garhwal and Kumaon region respectively. Highest values 6.98 mg/l of lead were observed in river Bhela Kashipur of Kumaon region followed by 0.98 mg/l at Haridwar down stream at river Ganga where sewage from cities along the river and industrial effluent may be predominated sources. Copper detected in 111 samples with mean value of 0.76 mg/l and 4.03 mg/l respectively in Garhwal and Kumaon region. Highest value of Cu 7.30 mg/l was detected in river Kosi of Kumaon region at the point where this river enters to another state boundary. This river suppose to carry effluent load of the industries situate din the Uttarakhand. In Garhwal region highest value of Cu 3.69 mg/l was observed at river Bhagirati down stream of Utterkashi. This area is influenced by large construction activities for Hydro electric power projects. Iron was observed in all samples with mean value 0.25 mg/l and 0.95 mg/l in Garhwal and Kumaon region respectively. Zinc was detected in 108 samples and the mean values are 0.09 mg/l and 0.08 mg/l in Garhwal and Kumaon region respectively. Highest value of Zn 0.64 mg/l was found at Haridwar down stream. Iron and Zinc did not show many variations which clearly indicate the dominant lithological weathering origin. All observed values of lead, 02 observation of the Cu, 59 observations of Fe were exceeded with the WHO standard for drinking water. 83 observations of Pb, 110 observations of Cu and 59 observations of Fe were found to be exceeded with the BIS Standards. As compare with the standards for fresh water as prescribed under Environment (Protection) Rules, 1986 none of the water body w.r.t. Pb (at the point where from the sample was drawn) except those where Pb was found not detectable was found suitable for fishing, Mari culture and even restricted for eco sensitive zones, 40 locations where Fe exceeded with 0.5 mg/l were not suitable from drinking, fishing, industrial cooling. None of the sample of Zn was found to be exceeded with WHO and BIS.

In the present study all metals show negative correlation with DO and pH mean more organic load in the water bodies more will be the concentration of heavy metals because organic matter provide surface for lechation of metals in acidic conditions. Metals showed positive correlation with Electrical Conductivity. Higher concentration of TDS and TSS along with EC may be result of rock-bed interaction with flowing water. High relief, tectonic disturbance and large scale human interventions may be responsible for higher sediment load in Indian rivers and thus result in high TDS and TSS which simultaneously could be the region for positive correlation of EC with metals in the present study. All metals showed positive correlation with each other in the present study. Lead showed strong positive correlation with Cu and Fe, where Cu and Fe itself strongly positive correlated.

Data were alanysed stastically by using ANNOVA on MS EXCEL and it was found that Distribution of Fe in river Yamuna System and Zn in Kumaon rivers during the four seasons is significantly difference at 90% level of significance. However all the metals in different river systems not show and significant difference temporally even at 95% level of significance. Spatially all the metals have shown very significant difference in their distribution amongst different river systems.

Temprature and Total Dissolved Solids in river Ganga System, Turbidity and Total hardness in river Yamuna System are showing significant difference temporally at 95% level of significance. Dissolved Oxygen and Phosphate in Kumaon rivers is found significantly differ at 80% level of confidence. While analyzing spatially, Phosphate and Total Hardness are not shown any significant difference. However remaining parameters have shown highly significant difference in their spatial distribution amongst different river systems.

Data of pollution load has been complied since Jan 2006 to October 2010 and computed for next 10 years for trend analysis by using linear regressing analysis. This was applied in river Kosi, Dhela and Bhela which are found more polluted in the present study. In river Dhela pollution load, if entering at present rate, will increase up to 8000 KG/day in 2020 while it is at present 4000-5000 Kg/day. In river Bhela, no significant change is found it will increase from 1500 to 1700 Kg/day at the end of 2020. Similarly in river Kosi pollution load will increase from 1700 to 3000 KG/day in the coming 10 years. From the above analysis and data collected it is found that pollution load in the aforesaid rivers is due to discharge from Pulp and Paper Mills.

From the review on pulp and paper industries waste water treatment, it is found that advance technologies such as membrane technology, fungal treatment and Activated sludge with ozonation are helpful in reducing the pollution load very significantly. These technologies were implied in lab to treated effluent of pulp and paper mill after conventional treatment. It is found that Membrane technology will reduce the organic load in effluent by 95%, Fungal treatment will reduce up to 57% and Activated sludge process with ozonation will reduce organic load up to 69% in the treated effluent. If these technologies will applied in all paper mills it will definitely reduce pollution load in the river and improve the river water quality in due course of time.

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CHAPTER-1 INTRODUCTIION

1.1 OVERVIEW

Fresh water is most precious for all living organisms. Ironically, availability of safe potable water is still a problem of majority of population. For several decades, developing countries have been leading the world in the pace of urbanization, which results in industrialization, deforestation etc the water resources adversely affected both qualitatively and quantitatively. As per United Nations report 1996, during 1990-1995, the average urbanization rate in developing countries including South Asia, were over 3.4% compared to only 0.7% in developed countries. In the water sector, it can cause two types of impacts: high demand of water and serious pollution of available water resources, which is presently viewed as top environmental problem in Asia region (ADB, 1997). In the context of South Asia region, specifically in Nepal, India and Bangladesh, pollution of surface water become more severe and critical near the urban areas due to high pollution loads discharged within short stretches of rivers and failure to provide adequate urban sanitary infrastructure along with lack of effective implementation of necessary pollution control measures (UN 1998). Rapid industrialization and urban development results in inclusion of variety of pollutants into rivers (CPCB, 2004) including heavy metals having geological origin and entry into river bodies by weathering and erosion (Zhang and Huang 1993) and due to anthropogenic activities like mining, discharge of industrial and domestic effluent (Abbasi et al. 1998). Anthropogenic activities like mining, disposal of treated and untreated toxic waste, and metal chelates (Amman et al. 2002) from different industries resulted in deterioration of water quality rendering serious environmental problems. Discharge of heavy metals with industrial effluent of pulp and paper mills (Ali and Rahman 2008) and Distilleries (Tewari et al 2006) were also reported. Due to rapid industrialization and flow of urban population in past few years is suspected to deterioration of water quality of ecologically rich Himalayan State of India namely Uttarakhand. There have been several studies on water quality monitoring of rivers flowing through Uttarakhand (Chakrapani, 2002; Semwal and Akolkar, 2006; Okendro et al. 2007; Bhandari and Nayal, 2008; Sati and Paliwal, 2008; Singh et al. 2008; Kaushik et al 2009; Kumar and Bahadur 2009). However, none of the study gives holoistic picture of surface water quality of major water bodies carried out at the same time.

1.2 ENVIRONMENTAL FACTORS OF RIVER WATER QUALITY

River water quality is highly variable by nature due to environmental conditions such as basin lithology, vegetation and climate. In small watersheds spatial variations extend over orders of magnitude for most major elements and nutrients, while this variability is an order of magnitude lower for major basins. Standard river water for use as reference is therefore not applicable. As a consequence natural waters can possibly be unfit for various human uses, even including drinking. There are three major natural sources of dissolved and soluble matter carried by rivers: the atmospheric inputs of material, the degradation of terrestrial organic matter and the weathering of surface rocks. These substances generally transit through soil and porous rocks and finally reach the rivers. On their way, they are affected by numerous processes such as recycling in terrestrial biota, recycling and storage in soils, exchange between dissolved and particulate matter, loss of volatile substances to the atmosphere, production and degradation of aquatic plans within rivers and lakes etc. As a result of these multiple sources and pathways, the concentrations of elements and compounds found in rivers depend on physical factors (climate, relief), chemical factors (solubility of minerals) and biological factors (uptake by vegetation, degradation by bacteria). The most important environmental factors controlling river chemistry are:

- Occurrence of highly soluble (halite, gypsum) or easily weathered (calcite, dolomite, pyrite, olivine) minerals
- Distance to the marine environment which controls the exponential decrease of ocean aerosols input to land (Na^+, CI^-, SO^-, and Mg^{2+}).
- Aridity (precipitation/runoff ratio) which determines the concentration of dissolved substances resulting from the two previous processes.
- Terrestrial primary productivity which governs the release of nutrients (C, N, Si, K).
- Ambient temperature which controls, together with biological soil activity, the weathering reaction kinetics.
- Uplift rates (tectonism, relief) Stream quality of unpolluted waters (basins without any direct pollution sources such as dwellings, roads, farming, mining etc.

1.3 RIVER WATER POLLUTION

Most of the Indian rivers and their tributaries viz., Ganges, Yamuna, Godavari, Krishna, Sone, Cauvery Damodar and Brahmaputra are reported to be grossly polluted due to discharge of untreated sewage disposal and industrial effluents directly into the rivers. These wastes usually contain a wide variety of organic and inorganic pollutants including solvents, oils, grease, plastics, plasticizers, phenols, heavy metals, pesticides and suspended solids. The indiscriminate dumping and release of wastes containing the above mentioned hazardous substances into rivers might lead to environmental disturbance which could be considered as a potential source of stress to biotic community.

As for example, River Ganges alone receives sewage of 29 class I cities situated on its banks and the industrial effluents of about 300 small, medium, and big industrial units throughout its whole course of approximately 2525 kms. Identically Yamuna is another major river, has also been threatened with pollution in Delhi and Ghaziabad area. Approximately 5,15,000 kilolitres of sewage waste water is reported to be discharged in the river Yamuna daily. In addition, there arc about 1,500 medium and small industrial units which also contribute huge amounts of untreated or partially treated effluent to the river Yamuna every day. In addition to domestic and industrial discharge into the rivers, there were continued surface run off of agricultural areas, mines and even from cremation on the river banks. According to a report, over 32 thousand dead bodies were cremated at the major burning Ghats per year in Varanasi alone in the year 1984.

1.4 POLLUTION IN THE GANGA RIVER

The Ganga Basin, the largest river basin of the country, houses about 40 percent of population of India. During the course of its journey, municipal sewages from 29 Class-I cities (cities with population over 1,00,000), 23 Class II cities (cities with population between 50,000 and 1,00,000) and about 48 towns, effluents from industries and polluting wastes from several other non-point sources are discharged into the river Ganga resulting in its pollution. The NRCD records, as mentioned in audit report, put the estimates of total sewage generation in towns along river Ganga and its tributaries as 5044 MLD (Million Litres per Day). According to the Central Pollution Control Board Report of 2001, the total wastewater generation on the Ganga basin is about 6440 MLD. Many towns on the bank of the Ganga are highly industrialised. Most of the industries have inadequate effluent treatment facilities and dump their wastes directly into the river. A high concentration of tanneries in Kanpur has further aggravated the situation. Besides other chemical and textile industries, Kanpur has 151 tanneries located in a cluster at Jajmau along the southern bank of the Ganga with an estimated waste water discharge of 5.8 to 8.8 million litres per day. Out of 151 tanneries in Jajmau, 62 tanneries use exclusively the chrome tanning process, 50 tanneries use vegetable tanning processes, and 38 tanneries use both chrome and vegetable tanning. The Indian government under the Ganga

Action Plan (GAP) has implemented several schemes for the abatement of pollution of the Ganga by tanneries. However, there are violations of the pollution control measures, and tannery effluents are still found in the river.

1.5 POLLUTION IN THE YAMUNA RIVER

River Yamuna is the primary source of drinking water for Delhi, the capital of India, and also for many cities, towns and villages in the neighbouring states of Uttar Pradesh, Uttaranchal and Haryana. In the last few decades, however, there has been a serious concern over the deterioration in its water quality. The river has been receiving large amounts of partially treated and untreated wastewater during its course, especially between Wazirabad and Okhla, National Capital Territory (NCT) of Delhi. Pollutants flowing into the river are contributed from the waste of the cities situated along its bank.

1.6 IMPACT OF RIVER WATER POLLUTION

The pollutants include oils, greases, plastics, plasticizers, metallic wastes, suspended solids, phenols, toxins, acids, salts, dyes, cyanides, pesticides etc. Many of these pollutants are not easily susceptible to degradation and thus cause serious pollution problems. Contamination of ground water and fish-kill episodes are the major effects of the toxic discharges from industries. Discharge of untreated sewage and industrial effluents leads to number of conspicuous effects on the river environment (Table 1.1). The impact involves gross changes in water quality viz. reduction in dissolved oxygen and reduction in light penetration that’s tends loss in self purification capability of river water.

Table 1.1: Environmental implications of the discharge of sewage and industrial effluents

S.N.	Factor	Principal environmental effect	Potential ecological consequences	Remedial action
1.	High biochemical oxygen demand	Reduction in dissolved oxygen	Elimination of sensitive species, increase in some	Pretreatment of effluent, ensure

	(BOD) caused by bacterial breakdown of organic matter	(DO) concentration	tolerant species; change in the community structure	adequate dilution
2.	Partial biodegradation of proteins and other nitrogenous material	Elevated ammoniaco ncentration; increased nitrite and nitrate levels	Elimination of intolerant species, reduction in sensitive species	Improved treatment to ensure complete nitrification; nutrient stripping possible but expensive
3.	Release of suspended solid matter	Increased turbidity and reduction of light penetration	Reduced photosynthesis of submerge plants; abrasion of gills or interference with normal feeding behavior	Provide improved settlement, insure adequate dilution
4.	Deposition of organic sludges in slower water	Release of methane andhydrogen as sulphide matter decomposes anoxically, Modification of substratum by blanket of sludge	Elimination of normal benthic community loss of interstitial species; increase in the species able to exploit increased food source	Discharge where velocity adequate to prevent deposition
Other poisons				
1.	Presence of poisonous substances	Change in water quality	Water directly and acutely toxic to some organisms, causing change in community composition; consequential effect on pray- predator relation; sub- lethal effects on some species	Increase dilution

Inert solids				
1.	Particles in suspension	Increased turbidity. Possibly increased abrasion	Reduced photosynthesis of submerged plant. Impairing feeding ability through reduced vision or interference with collecting mechanism of filter feeders (e.g. reduction in nutritive value of collected material).Possible abrasion	Improve settlement
2.	Deposition of material	Blanketing of substratum, filing of interstices and/or substrate instability	Change in benthic community, reduction in diversity (increased number of a few species)	Discharge where velocity adequate to ensure dispersion
Source: **Dr Sudheer Kumar Shukla,** Indian river systems and pollution On http://www.eoearth.org/article/Indian_river_systems_and_pollution?topic=58075				

1.7 HIMALAYAN RIVERS

The Himalayan Rivers have an important place in Indian culture and tradition. They are the lifeline of majority of population in cities, towns and villages and are considered sacred. Mass bathing in water bodies is an age-old ritual in India and an important in site utilization of water bodies, which demand water quality equally suitable to that required for drinking purpose. A number of pilgrims visiting holy places for bathing settle nereby river banks. Their daily routine near the water course become a constant source of contamination of water bodies. Apart from washing with detergents, pilgrims offer milk, curd, flower, coins, idols, ashes of departed ones and other religious matter into water bodies. Lack of control mechanism on such activities results in water pollution.

Domestic waste water is another area of concern for water pollution. At many occasions Himalayan rivers receive huge quantity of untreated sewage either directly into the rivers or due to inadequate sewage treatment facilities. A majority of human settlements exist on the hilly course of rivers and hotels, lodges, restraints situated over there dispose their waste water directly into the water bodies. Religious travelling in the hills results in floating population. This activity ultimately increases the volume of waste water into water bodies and thus contaminated the rivers. Due to rapid increase of urbanaistion, industrial development also took place at very fast rate. There are so many industries are coming at the cost of Himalayan rivers particularly in Himalayan state like Uttarakahnd. Out of these industries many are highly polluting in nature and discharges huge quantity of pollutants into water bodies. Pulp and Paper mills, Automobile manufacturing, Pharmaceuticals, metal finishing Dairy are the important sectors of industries which results in input of huge quantity of waste water alongwith toxic pollutants and organic load.

The Himalaya serves as the perpetual reservoirs of water for most of the main rivers which are of immense value to the northern India. The region is drained by numerous rivers and rivulets, locally known as gad, gadhera or raula. The northern parts of the districts of Chamoli and Uttarkashi, most parts of which lie under the snow-covered zone, provide the most important reservoirs of water. These rivers flow parallel to the mountains but at some places, these rivers turn into acute bend resulting in the formation of deep gorges. Lakes and tals of various shapes and sizes are also important water features of the region. The whole drainage system of the Garhwal Himalaya falls under the following systems:

1. The Ganga System

2. The Yamuna System

3. The Ramganga System

1.7.1 The Ganga System: The whole of Garhwal Himalaya, except western-parts of Uttarkashi and Dehradun districts and a small tract lying in the eastern margin of the Garhwal district, is drained by the Ganga system. The Alaknanda and the Bhagirathi after joining at Devprayag is conclusively called the Ganga and it finally descends into the plains at Hardwar. The Bhagirathi and the Alaknanda originate from the opposite sides of the Chaukhamba peak (7, 138m). After flowing in the opposite directions they bend towards Devprayag, forming a garlanded shape.

The whole Ganga system may be divided into three main sub-systems:

(i) The Alaknanda Sub-system

(ii) The Bhagirathi Sub-system

(iii) The Nayar Sub-system

(i) The Alaknanda Sub-system: The Alaknanda is the main river of this system which bubbles out from Alkapuri glacier (Dev Tal). The Saraswati River which also originates at Devtal, meets the Alaknanda near Mana Village, about 3.0 km north of Badrinath temple. The Dhauli Ganga takes its origin from Kuling in Niti and joins the Alaknanda at Vishnuprayag. The Girthiganga and the Rishiganga are the main tributaries of Dhauliganga. The Alaknanda flows in a narrow gorge from Vishnuprayag to Pakhi. The first sizeable river terrace (Bagar) of the Alaknanda appear at Pipalkoti which is about 1.6 km in width. The following are important tributaries of the Alaknadna.

(a) Birahi Ganga: Taking its origin from Nandaghunti, it flows in westward direction and joins the Alaknanda at Birahi (Kakudhar). There was a famous Gohna tal (Birahi Tal) in the valley of this river having 1.6km in length, 0.8 km in width and 100m in dpth, which gave way in 1898 for the first time and in

1970 for ever. The Puri Gad is important tributary of the Birahi ganga.

(b) **Nandakini:** It takes its origin from the estern slope of the Trishul and after flowing for about 75 km towards the west, it meets the Alaknanda at Nandprayag.

(c) **Pinda river:** The river originatses from the pindari glacier in the Almora district. Throughout its course, the river flows from southeast to northwest and meets the Alaknanda at Karnaprayag. The Kali Gad, with its tributary Gyanganga, is the main tributary of the Pindar draining in the upper part of the valley. After this confluence-point, the whole course of the Pindar is wide.The Pranmati Gad and the Ata Gad are other important tributaries meeting the Pindar from north and south respectively.

(d) **Mandikini:** It originates from the Kedar Himal, after flowing almost in north-south direction, it meets the Alaknanda at Rudraprayag. Its main tributaries are-Kaliganga, Mandani and Madmaheshwar. All these meet the Mandakini at its left side in its upper valley. Agastmuni and Sauri are the main river terraces (Bagars) of this valley while towards Rudraprayag or down streams, there are deep gorges. During monsson season of 1998, the Madhmaheshwar Ganga experienced devasting series of landslides, followed by formation of lake in the main channel which lasted for few weeks.

(ii) **The Bhagirathi Sub-System:** Major part of the Uttarkashi and Tehri districts is drained by this system. The Bhagirathi originates from the Gomukh (3,940m) and after flowing for about 18 km westwards, river Janhavi meets it at Bhaironghati. The uppermost tip-tributary of the Janhavi are Barigun Gaf and Chor Gad. The Bhagirathi flows almost in north-south direction between Harsil and Maneri and between Maneri and Dunda, the river flows in almost east-west direction for about 30 km. After Dunda, the course of Bhagirathi is from northwest to southwest till it meets the Alaknanda at devprayag. The Jalandhari Gad, Siya Gad and Pilang Gad are main tributaries of the Bhagirathi between Harsil and Maneri. The Dhaneri, Nagun Gad and Jalkur river are main tributaries between Dunda and Tehri.

The Bhilangana, the only sizeable tributary of the Bhagirathi, takes its origin from the Bharti Kantha in the northeastern part of the Tehri District and joins the Bhagirathi at Ganeshprayag, near Tehri. The Balganga (renamed as Balkhila) rising from the Shastratal is the main tributary of the Bhilangana which meets it at Pilkhi. Other tributaries are-Dharamganga, chanji Gad, Nailchami Gad, etc. The Bhilangana system drains eastern part of Tehri District. the Bhagirathi and the Bhilangana have formed deep and broad valleys with extensive river terraces like Chham, Pilki, Chamiyala, Sirain, etc.

(iii) **The Nayar sub-system:** The Nayar, consisting of two branches, the western and the eastern Nayar, is a compact system of drainage which drains most parts of the Garhwal district. Both the river rise in the Dudhatoli range. The western Nayar at first flows almost due north but soon turns to the west and southwest and after draining for about 77 km, finally reaches the junction at Bhatkoli, near Satpuli. The eastern Nayar flows southwest as far as kainyur, near Thalisain, then southwards till it reaches the border of Khatli pati, then truns sharply to the west and northwest till it reaches the junction. Its total length is about 129km. After the confluence of these two rivers near Satpuli, the unites stream then flows for about 32km in the northwestern direction and meets the Ganga near Vyasghat. The upper part of the Nayar valley is wide with thickly populated villages but the lower valley generally passes through steep hillsides and hence, less cultivated.

1.7.2 The Yamuna System: The western part of Uttarkashi district is drained by the Yamuna System (Yamuna-Tons basin). The Yamuna has its source in the Yamunotri glacier which lies on the southerwest slope of the Bandar Punch peak. After draining most of the part of Uttarkashi district, the Yamuna touches the western boundary of the Tehri district at village Bhatgaon. Here, it separates the Dehradun district from northwest. The Badri Gad and the Aglar Gad are the two important tributaries of Yamuna in Tehri district which, after rising from the Nagtibba and the Srikanda peaks, join the Yamuna from its left near Parogi and Bhanan respectively. In Tehri district, only western parts of the Jaunpur block is drained by the Yamuna system.

The Tons, the biggest tributary of the Yamuna in the Himalayan region, takes its origin from the northern slope of the Bandar Punch peak and , flowing in a valley northwest of the Yamuna, joins the latter below Kalsi and thereafter the Yamuna enters the plains. From Kalsi, the Yamuna flows along the boundary with Himachal Pradesh, west of district Dehradun. The Tons, though is a tributary of the Yamuna yet it brings nearly double the volume of water of the Yamuna.

1.7.3 The Ramganga System: A number of small streams originating from the Chorkhaldhar and the Khankarkhet ridges of the Dudhatoli range from the upper tip-tributaries of the Ramganga. As soon as it flows eastward from Mahalchauri, the river reaches in the Almora district and draining through Chaukhutiya, Masi and Bhikiyasain, it again enters the district of Garhwal, a little ahead of Dewal. The Mandal, largest Siwalik river of the eastern Garhwal, meets the Ramganga at Loharchaur and a little below the Palain Nadi traversing through the Patali dun, meets the Ramganga at Buksar. Maon it enters the Bhabar area at Kalagarh and further drains the Bijnor district. RiverKosi, Dhela, bhela, Gola, Kailash etc are flowing in the Kumon region are main tributaries of river Ram Ganga.

The drainage system in the Siwalik and the Bhabar region, lying in the southern part of the Garhwal region, reveals some salient characterstics. Except the Ganga and the Ramganga, almost all the rivers of this region dry up during summers and other dry periods. On the other hand, floods generally occur during monsoon period. Most of these rivers make high gradient hence, they come down at very fast rate with huge loads of the Siwalik debris. Here, they generally inherits two major systems of drainage (i) The Ganga system, covering the western part and (ii) The Ramganga system, draining the western part.

1.8 DEFINITIONS

Present study was carried out in the state of Uttarakhand, nourished by many important rivers of India including river Ganga and Yamuna. The State of Uttarakhand borders Tibet on north, Nepal on east, and the states of Himachal Pradesh and Uttar Pradesh in west and south respectively. Uttarakhand lies between geo-coordinates from 30^{0}19’48” N to 78^{0}3’36” E. Uttarakhand has geographical area of 53566 Sq Km. Out of the total area, about 85% is hilly/forest/glacier area and remaining 15% area is burdened with most of the commercial activities. The whole state of Uttarakhand is divided into two geographical areas namely Garhwal and Kumaon area. Garhwal area is nourished by river Ganga, Yamuna and Tons, while the river Kosi, Ramganga, Gola etc. are flowing through Kumaon area. Almost all the water bodies of Kumaon region, presented in this paper, are of non-glacier origin and mainly seasonal rivers.

1.9 OVERVIEW OF RESEARCH MODEL

The present study will be carried out with following objectives:

i) **To assess pollution load in major rivers of Uttarakhand and try to analyze the impact of domestic and industrial effluent.**

ii) **To review the technologies for better treatment of effluent i) up gradation of modern effluent treatment technologies in paper Mill industrial sector, ii) strategies for decentralized domestic waste water treatment system in hilly areas, so that the river quality may receive treated waste water.**

1.10 OVERVIEW OF RESEARCH APPROACH

Present research is based on the water quality data generation in laboratory of river Ganag, Yamuna, Kiumaon river and Naini Lake at various locations and at different seasons. Industrial waste water data is collected from respective Government departments. Extrapolation the pollution load in rivers and vis-a-vis water quality of rivers is also carried out. Advance technologies for waste water treatment in polluted industrial sector are also tested for significance for reduction in pollution load.

1.11 OUTLINE OF THESIS CHAPTERS

This thesis is covered by the following chapters:

1. Literature survey contains previous studies on the related aspects.
2. Material and Methods describe about the methodology used for the present study. Detail of analytical procedure has been described in this chapter.
3. Results and discussions are presented in a separate chapter.
4. References and Apendix.

CHAPTER-2 REVIEW OF LITERATURE

This chapter reviews the literature relevant to the present study. The literature review is focused on contemporary work being done on water quality analysis, weathering control and factors controlling the water chemistry etc. a summary of the previous work relevant to the hydrochemistry, major ion and trace clement chemistry carried out by various researchers at national and international level and in and around the study area are included in this chapter. Variation of water quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities. Knowledge on hydrochemistry is more important to assess the quality for understanding its suitability for various needs and also to evaluate the aspect of chemical weathering of rocks. A number of studies have been carried out at national and international level.

2.1 RIVER WATER QUALITY

Globally, weathering of rocks is the major source of ions in the water bodies. Physical chemical and biological processes are involved in rock weathering. The chemical reactions between rock minerals and soil water produce cations, anions and heavy metals in surface and groundwater. The chemical composition of the world river has been reviewed by Meybeck (1979). This compilation provided a general idea of chemical composition of rivers flowing through different geological terrains and climatic regimes. It can be observed from the data compiled by Livingstone (1963) and Meybeck (1976) that ionic rations in the water of Major River are fairly constant. Among cations Ca were found to be most abundant cation while among anions HCO_3 were found to be most abundant anions in water. This is the case for more than the 90% of the rivers which have rock dominant type of the water described by Gibbs (1970). The remaining rivers are Na, Cl, SO_4 ion dominant type where water is either rain dominant type or the evaporation –crystallization types (Gibbs, 1970). The rock-dominated type of waters reflects the weathering of minerals found in surface rocks, particularly the calcium carbonate minerals in sedimentary rock. He found that the chemistry of river water is influenced by precipitation, rock interaction and evaporation. Gibbs (1970) plotted TDS verses the Na/Na+Ca, the two end member of sea water and of fresh water and showed the mechanism controlling water chemistry in river. Rivers with Na/Na+Ca between 0.2 to 0.6 and TDS concentration approximately between 90mg/l to 450 mg/l owe most of the chemical composition due to rock weathering.

Weathering of both silicate and non silicate rock contribute -70% of river alkalinity while remaining 30% is caused by river based biological processes due to decomposition of organic matter Probst et al. (1998). The relative weathering contribution in the beginning of monsoon season is likely to be high due to large discharge of various river systems flushing out weathered top soil in the initial stages of rain water when biochemical reactivity is inhibited by rapid flow of water.

The chemistry of some of the large rivers of the Asian region such as the Ganges, Brahmaputra, Changjiang and Huanghe have been studied extensively by a number of workers, Raymahasay, (1970), Hu et al., (1982), Abbas and Subramanium, (1984), Sarin and Krishnaswami, (1982), Sarin et al. (1989), (1990), Chakrapani et al., (1995), Bhatt and Saklani (1996). The water chemistry of the Indus in Pakistan was studied by Meybeck (1976). In India some of the tributaries of the Indus were studied by Subramanian (1979) and Pande et al. (1994).

Chakrapani's (2005) studies on major and trace element geochemistry in upper Ganga river, Himalaya found large seasonal variation in major element concentration. The water type was categorized as HCO_3^-, SO_4^{2-}, Ca^{2+} dominant which constitute >60% of the total water composition. It was observed that only

5-12% of bicarbonate is derived from silicate lithology indicating strong influence of carbonate lithology on water chemistry in the head waters of Ganga river. More than 80% Na^+ are derived from silicate lithology.

Further major south Asians rivers reveals strong seasonal variation in their solute transport reflecting variable export of silica, Ca, Mg and alkalinity in response to seasonal changes in i.e. precipitation and temperature. The value for alkalinity, Ca and Mg in winter season are generally higher than summer season in downstream region of river Indus in Pakistan, (Karim and Veizer 2000). Similar variation were also observed for the river Indus from Lakakh Himalaya (Ahmed et al., 1998) as well as for Ganga and Brahmaputra. Feleke et al. (2007) studied fluoride in groundwater in the rift valley region of Ethiopia and reported that dental and skeletal fluorsis is common health problem in the region due to drinking of high fluoride water (up to 33 mg/L fluoride).

Mangore (2007) evaluated the groundwater quality for industrial, commercial and domestic uses in Bulawayo, Zimbabwe and 27% of the samples are positive with respect to total colifrom and 8% with respect to fecal coliform. The study reveals that leaks from industrial and domestic sewers from the old sewer lines is the cause of this pollution. Further they observed that the groundwater quality is being adversely affected by land – use related activities. Sadek and El-Sami (2001) studied the susceptibility of quaternary aquifers in infiltration of domestic sewage and discharge of untreated industrial wastewater into the subsurface aquifers. Similarly numerous studies (Barrett et al., 1999 and Cronin et al., 2003) carried out on the aquifers underlying the city of Nottingham in the UK, revealed that sewer leakages have an impact on the groundwater quality. Korfali and Jurdi (2003) investigated the water quality of free flowing river and reservoir in Lebanon and found that the reservoir with catchment area having agricultural and industrial activities had a high pH (8.4) than the free flowing river, which received domestic wastewater (high carbon dioxide content) and observed significant differences in the water quality of the two water bodies. They attributed differential water quality of two water bodies to the nature of the water resources and the exposure to the contaminants. Cronin et al., 2003 has also made an attempt to characterize the spatial and temporal variations in sewage-related microbial and anthropogenic – related inorganic contamination of the aquifer in U.K. Hajalilous et al (2009) had investigated hydro chemical factors and groundwater quality assessment in Marand Municipality, northwest of Iron and extracted three parameter based on factor analysis.

The rivers draining the Himalaya contribute significantly to the global sediment and water discharge (Milliman et al., 1983). They have recently attaracted attention of several workers in the Himalaya and global climate (Raymo and Ruddiman, 1992) as silicate weathering is thought to be a global sink for CO_2 on geologic time scales (Berner, 1995). Such a hypothesis has led to a number of studies on rivers driaining the Himalaya (Krishnaswami et al., 1992, Sarin et al., 1992; Pande et al., 1994, Galy and France-Lanord, 1999). These studies are based mainly on isotopic and major ion composition of dissolved load of rivers. The major ion chemistry and chemical weathering in Ganga basin has been carried out by several workers, notably among them are Trevedi et al (1992), Sarin et al 1992, Abbas and Subramanian (1984) etc. Sarin et al (1984) carried out major ion and isotope chemistry of high land and low land river of Gang and Brahamputra basin and observed that the chemistry of high land river was dominated by weathering of carbonate rocks present in the basin and silicate weathering in these drainage basin is of minor importance. The seasonal variation in these rivers indicated that during lean flow (premonsoon season) the contribution from alkaline and saline salt effected soil is more pronounced and during peak flow (post monsoon) the chemical composition of these rivers closely follow that of “rock dominant” type of water. Study on major ion chemistry and weathering control in a high altitude basin at Alaknanda river Garhwal Himalaya was carried out by Singh and Hasnain (1998). They observed that among anions, bicarbonate is the most dominating anion (78%) with minor contribution of sulphate (19%), and chloride (3%). It has been concluded that rock wathering is the most important mechanism controlling the water chemistry and water chemistry of the basin is controlled by carbonate weathering and partly by silicate weathering. The seasonal and spatial variation in TDS was attributed to climatic and lithological control over ionic concentration.

Dalai et al., (2002a, b, c and 2003), carried out a part of detailed geochemical and isotopic investigation of the Yamuna River System (YRS) in the Himalaya (i) to characterize chemical weathering in the YRS basin and (ii) to assess relative mobility of elements during weathering and transport. He found that carbonate weathering is contributing to jajor ion composition of Yamuna water.

However, geochemical studies of sediments in the headwaters of rivers in the Himalaya are limited. Variable geochemical studies of river sediments in the India Himalaya include reconnaissance survey of the Ganga and the Yamuna (Subramanian, 1987, Jha et al., 1990; Chakrapani and Subramanian, 1996; Subramanian and Ramanathan, 1994, Ramesh et al., 2000 and the Indus (Ahmed et al., 1998).

The sediment loads of Asian rivers are reported to be the highest in the world, delivering approximately 80% of the global sediment input to the oceans (Holeman, 1969). A total of 1.8 Gt $year^{-1}$ of suspended sediments or 9% of the total annual load arried from the continents to the oceans (worldwide) are transported in three river systems, the Gang, Indus and Brahmaputra, in a combined runoff of 1.19 x 10^3 km^2 (Meybeck, 1976). These large sediment loads are due to the exposure of the geologically young rocks forming the Himalayan mountain chain, which has the world's greatest range of relief and extremes of climate.

Alkalinity load and dissolved silica is shown to be related with land use pattern and therefore prone to the anthropogenic alteration. Lesser Himalayan studies indicate that steep relief, resulting in abundant supply of eroded material, is not a limiting factor in case of Himalayan rivers, West et al. (2005).

Maheswari et al., (2007), while assessing Impact of Coffee Processing waste water on river water quality found that the pH of water is acidic in coffee processing season and neural in off season in Kodwar river and the pollution level of the Kodavanar river water was slightly higher than the prescribed limits during the coffee processing season (September to January) in comparison with the off season.

Kumar et al. (2007) while studying hydro geochemistry in national capital city Delhi found that the EC, SO_4, NO_3 and PO_4 concentration wee high in all season and weathering of carbonate, silicate minerals and ion exchange and surface water interaction seems to be major control on water quality of the region.

Rai et al. (2006), studied sedimentation rate and physic-chemical characteristics of Mansar, Dal and Wooler lake in Jammu & Kashmir and suggested that anthropogenic activities in recent year have greatly affected the hydrological regime of lakes for eg. Inflows of eroded material have accelerated eutrophication process.

Singh et al. (2005), conducted study of six reservoirs of Damodar River basin in pre- and post-monsoon, to study the major ion chemistry and the weathering and geochemical processes controlling the water composition. The seasonal data shows a minimum concentration of most of the ions in post–monsoon and a maximum concentration in pre-monsoon seasons, reflecting the impact of elevated temperature and increased evaporation during the low water level period of the pre-monsoon season. Water chemistry of the reservoirs strongly reflects the dominance of continental weathering aided by atmospheric and anthropogenic activities in the catchment area. Higher concentration of SO_4 and TDS in Panchet, Durgapur and Tenughat reservoirs indicte effect of mining and anthropogenic activities on water quality. The high contribution of (Ca+Mg) to the total cations, high concentration of dissolved silica, relatively high $(Na+K)/TZ^+$ ratio (0.3) and low equivalent ratio of (Ca+Mg)/(Na+K) suggests combined influence of carbonate and silicate weathering.

Sharma et al. (2005) reviewed the water quality status at different sources in the Central Himalayan Kingdom of Nepal. The study showed that water of inner and outer Himalaya is vulnerable to fecal pollution.

Jain (2002) undertook hydro chemical study of mountainous watershed of river Ganga and observed increased conductivity (330µS/cm) during low flow Periods and total dissolved solids (2002 mg/L) during mosoon periods due to high sediment concentration. The amount of nitrates and phosphates compounds is slightly high in the samples due to high agricultural activities in the catchment area. Hussain and Ahmed (2002) assigned th variability of physic-chemical parameters of river Pachin, Itanagr during different flow periods to dilution of river water by runoff, runoff, human activities and organic load. Bharathi and Krishnamurthy (1990) studied the effect of industrial effluent on the lotic habitat into river Kali in Dandeli, Karnataka.

Chakrapani (2002) studied Himalayan lake in Kumaun region namely: Nainital, Bhimatal, Sattal and Naukchiatal and found that water chemistry is dominated by Ca, Mg and CHO_3 indicating carbonate lithology the major source of ions. Chakrapani (2005) also studied major element geochemistry in upper Ganga river and found large seasonal variation. He observed that the water of the Ganga HCO_3^- SO_4^{2-} and Ca^{2+} are the dominant ions which constitute> 60% of total water composition land about 5-12% of HCO_3 and more than 80% Na^+ and K^+ were derived from silicate lithology indicating indicating the predominance of carbonate lithology on the ionic composition of Gang water. While carrying out geohydrological studies of the Gaula river basin, District Nainital, Bartarya (1988) has analyzed samples from springs, rivers and lakes and he observed (1993) dominance of $CaHCO_3$ hydro chemical faces over Ca-Mg-SO_4 faces and the chemistry of spring water present in the Lesser Himalayan rocks elucidated influence of rock types of their catchment.

Chronological order of research done and researchers and contribution

1	Mukherjee et al 1993	The water qualities of the River Ganga (The Ganges) over a short stretch from Swarupganj to Barrackpore (in West Bengal) have been determined and are compared with

		the values reported by the National Environmental Engineering Research Institute of India for the periods 1972-74 and 1979-80. The water quality is generally bad, but not at such alarming levels as previously determined by other agencies. Biochemical and chemical oxygen demand (BOD and COD) levels are high but within tolerable limits. Dissolved oxygen (DO) levels are are fairly high, indicating a reasonable self-purifying capability for the River Ganga. However, nutrient loads containing N and P have increased enormously in recent years.
2	Gupta et al (1997)	Ganges has snow covered semi-temperate upper reaches in the Himalayas while in the mid and down-stream reaches, some of its tributaries bring water from tropical system weathering soft volcanic rocks. Thus, water quality in different parts of the rivers varies widely simply due to differences in weathering pattern under local conditions.
3	Datta and Subramanian (1997).	The water quality of the combined Ganges-Brahmaputra river system in the Bengal basin area both in India and Bangladesh and concluded that the water chemistry is influenced by rock weathering in the upper reaches and atmospheric deposition (monsoon rain) in the lower reaches while in the mid-reaches, human impact is clearly visible.
4	Ittekkok et al (1999).	As the river flows through the mid-stream alluvial terrain with a large number of tributaries such as the Yamuna, Ram Ganga, Gomti, Ghagra, Gandak (all flowing from the Nepal Himalayas) and Sone (flowing from the Vindyan mountains in the south) with diverse lithology (hard rocks to unconsolidated sediments) representing wider geological age (Precambrian to Recent), the water quality shows enhanced

		values through major urban centres for a number of key parameters so that by the time the river reaches Kolkata about 2500 km downstream of the originating point, the chemical nature of the water is totally different reflecting both natural weathering and also contribution from anthropogenic input via a very large number of urban and industrial outlets in the mid-stream region.
5	Compendium of Environmental Statistics, 1999	Further, many reports of different water pollution control boards in India indicate that BOD (Biological Oxygen Demand) values are in excess of permissible levels for drinking water at practically all locations in the sub-continent.
6	Tariq et al., 1996, Shahid, 2000	The status of BOD in other river systems in the sub-continent is no better with very high values of BOD in excess of 50 mg/l for Indus at Karachi and BOD over 40 mg/l for rivers in Bangladesh.
7	Kazmi, 2000	The river Yamuna is moderately polluted in the stretch upstream of Delhi and heavily polluted in the Delhi Stretch. The pollution impact is the highest in low flow months. A surface water quality model – Mike 11, developed by Danish Hydraulic Institute – has been calibrated for the river for low flow months in the specific stretch with regard to BOD, DO and fecal coliforms based. The model has been verified to forecast the effect of pollution control schemes that have been proposed for the river
8	Pande et al 2000	The pollution of the Ramganga river in a stretch about 25 km around Moradabad has been studied. The pollution is caused by effluent wastes produced by nearly 450 electroplating units and entire brass and stainless steel industry, apart from the domestic wastewaters. The river at Moradabad manifests

		severe organic pollution and build-up of toxicants (heavy metals) particularly, the iron which has well exceeded its permissible limit.
9	Joshi et al 2001	A field study was conducted to assess the variation in physico-chemical characteristics of water of rivulets of Gomti basin watershed in Kumaon Himalayan region. The ionic status of the rivulets studied was found unsuitable for drinking, cooking, bathing and washing purposes without treatment. However, it was found suitable for irrigation in terms of the parameters studied
10	Karan and Harada, 2001	In South Asian countries such as Nepal, India,and Bangladesh, pollution of rivers is more severe and criticalnear urban stretches due to huge amounts of pollution loaddischarged by urban activities. The Bagmati River in the Kathmandu valley, the Yamuna River at Delhi, and peripheral rivers (mainly Buriganga River) of Dhaka suffer from severe pollution these days. Regression analysis reveals pollution loads steadily increasing nearly in step with the trend in urbnization. The dissolved oxygen (DO) level of the Bagmati and Buriganga rivers is declining at an average annual rate of nearly 0.3 mg/ liter/year. Unplanned urbanization and industrialization occurringin these cities may be largely responsible for this gravesituation.
11	Chakrapani, 2002	Four major Himalayan lakes in Kumaun region in India namely, Nainital, Bhimtal, Sattal and Naukuchiatal, have been studied to understand water and sediment geochemistry. The water chemistry is dominated by Ca, Mg and HCO3, an indication of a carbonate lithology source for the water composition. About 55–80% of Na and only 30–40% of Ca in the lakes are derived from silicate lithology.

		The Nainital lake is also characterised by a high chemical index of alteration, which is reflected in its high carbonate and the clay mineral content of the sediments. Model calculations show that 33 and 67% of nitrate in Sattal Lake is contributed by agriculture and cultural effects, respectively.
12	Chakrapani and Yadav, 2009	The Alaknanda and Bhagirathi rivers show significant variations in chemical compositions during different seasons. Carbonate rock weathering is responsible for more than 70% of the chemical compositions in the river waters. The chemical weathering rates show seasonal variations and are much higher during non-monsoon season.
13	Jain, 2002	A hydro-chemical study has been carried out on a 37-km stretch of the River Ganga from Deoprayag to Rishikesh (India) during the period from April 1999 to March 2000. The assessment of sediment and nutrient load has been considered to evaluate the current state of pollution through real time measurements. The values of pH and conductance are well within the limits prescribed for drinking water. The maximum suspended sediment concentrations of 1405 and 2002 mg/L were recorded at Deoprayag and Rishikesh, respectively, during the rainy season. Dissolved N and P from fertilizer application, sewage and non-point source run-off contribute significant quantities of the nutrients in river water. The nitrate and phosphate are transported from the cropland either by being adsorbed on to soil particles that are subsequently eroded, or dissolved in runoff water from agricultural land.
14	Goldar and Banerjee, 2004	Water quality in Indian rivers is carried out using water quality (water class) data for 106 monitoring points on 10 important rivers for five years, 1995–1999. As expected,

		river water quality is found to be positively related with rainfall, and negatively related with industrialization, irrigation intensity and fertilizer use. A significant positive relationship is found between poll percentage and water quality, and also between the rate of increase in literacy level in a district and the water quality in rivers flowing through the district. These results point to a significant favorable effect of informal regulation of pollution on water quality in rivers in India.
15	Subramaniam, 2004	There are significant differences in the water chemistry of the Himalayan and southern peninsular rivers. Large and small rivers also show different types of water quality. Liquid and solid waste definitely contributes to water quality in urban centres such as Delhi and even coastal regions, as near Mumbai, are affected by waste discharges. The sub-continent also suffers from problems associated with floride and also arsenic in different parts. Even drinking water shows contamination with metals and POP. Thus over one billion people, both qualitatively and quantitatively, are at water risk. The intensive agricultural activity in the sub-continent is reflected in enhanced levels of nutrients in various water bodies in many parts of the region. Thus, water in south Asia may be thought no longer to represent natural water quality but shows impact of different types of human activities practically in every part of the sub-continent.
16	Chandra sekhar and Umamahesh 2004	River Krishna in the Southern Peninsula of India is a typical receiving water body of both point and non-point discharges. Comparisons between upstream and downstream monitoring sites reveal changes in the concentrations and load to the river. This information is used to discriminate between point

		and non-point source contribution to pollution. The results of the mass balances indicate that non-point sources to be major contributors to the pollutant loads. The non-point sources in the study area predominantly include pollution due to agricultural practices and activities, soil erosion, dissolution of soil minerals or combination of these sources
17	Amaal and satar, 2005	Water quality of the River Nile from Idfo to Cairo and trace elements of the Nile water were seasonally investigated from autumn 2000 to summer 2001 at 11 sites. The distribution of major cations and anions possessed the highest values in cold seasons and the lowest during the hot high-flow period. In addition, EC, TS, TDS, COD, NH4+, orthophosphate, total phosphorus, Fe, Mn and Cu showed a steady increase from south to north. Point and non-point sources of pollution exerted negative local effects on the water quality of the receiving waters.
18	Chakrapani, 2005	Temporal and spatial sampling for a 1 year period (monthly intervals) was carried out in upper Ganga region and analyzed for dissolved major elements, trace elements, Rare Earth Elements (REE), and strontium isotopic compositions. The water type is categorized as HCO3 1)–SO4 2)–Ca2+ dominant, which constitute >60% of the total water composition. On an average, only about 5–12% of HCO3 is derived from silicate lithology, indicating the predominance of carbonate lithology in water chemistry in the head waters of the Ganga river. More than 80% Na+ and K+ are derived from silicate lithology.
19	Guru Prasad B, 2005	. The parameters like temperature, suspended solids, total solids, electrical conductivity, alkalinity, dissolved oxygen and chlorides are analyzed. For the experimental data mean,

		standard deviation, variance, and standard error are calculated and the results are discussed. This investigation revealed that the canal serves the purpose of human use.
20	Kallol et al 2005	Various physio-chemical parameters were assessed on the samples drawn from the river, “Koel”, “Shankha” and “Brahmani” selecting strategic points. It was observed that dilution during rainy season decreases the metal concentration level to a considerable extent. However the enrichment of these metals by bio-magnification and bioaccumulation in edible components produced in water is accepted to produce a remarkable effect on the water of the river “Brahamani” which is of deep public concern.
21	Samanta et al, 2005	Paper deals with the measurement of five heavy metals viz., Cd, Cu, Mn, Pb and Zn in water of the rivers Hooghly and Haldi at Haldia. Most of the metals exhibited their least concentration at the sampling site above the Haldia industrial area of river Hoogly. Comparison of the data with the Criterion Continuous Concentration (CCC) of USA revealed that Cd, Cu and Pb were the pollutants present at alarming level to disturb the aquatic life process in the zone. The other two metals viz., Mn and Zn were probably less harmful to the aquatic ecosystem.
22	Singh and Mathur p, 2005	Study deals with the physico-chemical studies of an ancient but famous fresh water lake ‘Ana Sagar’ Ajmer, Rajasthan. Data were collected over a period of six months. The result obtained in the investigation shows that this lake is highly polluted, its water is extremely alkaline and the nitrate and phosphates are high in comparison to standard limits as of an eutrophic lake.
23	Thilaga et al 2005	The Ooty lake in Tamil Nadu is currently heavily infested

		with water hyacinth and other aquatic weeds. The water was found to have significant quantities of nutrients including eutrophication causing nitrogen and phosphorus, which have arrived mainly due to discharge of municipal sewage and surrounding runoff. The phosphate has reached up to a maximum of 12.2 µg/ml which is much higher as far as eutrophication is concerned
24	Tiwari et al 2005	The physicochemical analysis of Ganga river in Bihar shows that the water has high TDS, TSS, BOD, and COD. The coliform bacteria were found to be alarmingly high in the river. Most of the parameters analyzed were found high near the bank in comparison to the water in the middle stream of that station. The study revealed that due to discharge of untreated sewage into the Ganga, the water quality of Ganga has been severely deteriorated and the potable nature of water is being lost.
25	Tiwary et al 2005	A study was carried out on Ganga river in Bihar region in and around Patna to assess the impact of sewage pollution on the water quality of the river. The physicochemical analysis of Ganga river shows that the water has high TDS, TSS, BOD, and COD. The coliform bacteria were found to be alarmingly high in the river. Most of the parameters analyzed were found high near the bank in comparison to the water in the middle stream of that station. The study revealed that due to discharge of untreated sewage into the Ganga, the water quality of Ganga has been severely deteriorated and the potable nature of water is being lost.
26	Vishnoi and srivastava, 2005	Water samples collected from three different sites of river Jojari at Salwasa, Jodhpur was subjected to hydrobiological studies. It was found that the pH, chloride, salinity, total

		alkalinity, total hardness, dissolved oxygen and TDS were absolutely higher than the standard values of portable water on account of contamination of river due to industrial effluents. The river has become unsuitable for the growth and survivability of aquatic flora and fauna. The pollution impact was found to be predominant during summer and minimal during monsoon season.
27	Chakrapani and Jan Veizer, 2006	Dissolved sulphate concentrations in the samples vary appreciably from a very low value of 47 mmol l–1 in the Mandakini river at Rudraprayag to a high value of 535 mmol l–1 in Jadhganga at Bhaironghati. River sulphate results mainly from dissolution of gypsum or oxidation of pyrites. Gypsum weathers faster because it goes into solution quickly and also gypsum beds occur as discrete beds, thus enabling selective removal during weathering. On the other hand, pyrite occurs as disseminated forms and requires breakdown of surrounding rocks before sulphate is released by oxidation
28	Das et al 2006	Experiments carried out at Subhas Sarovar (lake) and Rabindra Sarovar (lake), Kolkata, indicates that EC has a linear relationship with Total Dissolved Solids (TDS), which is validated by the findings at various other lakes throughout the world. It is also observed that EC increases with increase in TDS, which in turn indicates increased concentration of sulphates and other ions.
29	Kulshrestha and Sharma, 2006	Study highlighted that mass bathing during Ardhkumbh caused the changes in the river water quality and indicated that water is not fit for either drinking or bathing purposes. The presence of faecal coliforms in water also hints at the potential presence of pathogenic microorganisms, which might cause water born diseases. Although the water was

		found to be safe with respect to dissolved oxygen content, the values of BOD and COD exceeded the maximum permissible limit during bathing.
30	Yadav and Chakrapani, 2006	Chemical dissolution of bed rock/minerals plays a central role in determining the geochemistry of natural waters. The major source of dissolved species to natural water is the rocks coming in contact with water. As soon as the rocks come into contact with water, water–rock reaction starts and moves forward towards equilibrium by dissolving or leaching bedrock minerals into the solution. By this mechanism, major cations, anions, silica and other essential nutrients are released into the hydrosphere. The solute concentration in the water system is proportional to the reactivity of the bedrock minerals constituting the catchment. Thus, the chemical composition of natural waters is a direct indication of the geology of their catchment. Dissolution kinetics of rocks and minerals is important in understanding different rates of chemical weathering of various lithologies, development of soils, production of secondary porosity in the rocks, triggering of landslides and sequestration of atmospheric carbon dioxide. Recent studies on mineral weathering phenomena in inter-terrestrial materials and under space weathering conditions reveal the differences in chemical weathering under different physical and chemical conditions.
31	Semwal and Akolkar, 2006	The study deal with water quality assessment of rivers in Uttaranchal, in view of their religious importance and ecological sustainability. Out of 60 stretches of 19 rivers, 41 stretches indicated clean water quality of Class ‘A’, five stretches were slightly polluted (class ‘B’), six were

		moderately polluted (class 'C'), one stretch was highly polluted (class 'D') and there were altogether seven severely polluted (class 'E') stretches. Open defecation is the most common activity on river banks, which has significant contribution towards the aesthetic water quality of rivers.
32	Bhandari and Nayal, 2008	Present work deals with the assessment of physico-chemical parameters of water samples of Kosi river at Kosi sampling station during 2004 and 2005 in pre monsoon, monsoon and post monsoon seasons. It is found that an appreciable significant positive correlation holds for chloride with pH, Mg, Na, hardness and total suspended solid; and sodium with hardness, EC and sulphate. A significant negative correlation was found between potassium with turbidity, Cl-, EC and hardness. All the physicochemical parameters of Kosi water are within the highest desirable limit or maximum permissible limit set by WHO except turbidity and BOD which recorded a high value.
33	Eziz et al 2008	On the basic of the monitored data of Tuman River, Shanghai and statistics concerned with economic and social development of Tuman River basin, the water quality were evaluated. Five major pollutants were selected by factor analysis on 13 pollution indexes. Then the driving forces of the pollution of Tuman River were analyzed. The results showed that SS is the major pollutant in Tuman River. In arid zone, total suspended particulates have great influences on the water quality of urban river. Furthermore, industrialization, overpopulation and land use and land cover changes have influences on the water quality of urban river to certain extend, so human activities in arid zone should be cautious

34	Gupta and Chakrapani, 2008	We recognize three key factors that influence water and suspended sediment load of the Narmada river, namely basin geology, rainfall and presence of reservoirs/dams. In the present study, water flow and suspended sediment load data in the Narmada river have been assessed based on 20 years of monitoring at various gauging stations. Most of the water flow in the river is during the monsoon season, except in some tributaries, where groundwater flow to the river during non-monsoon is significant. The suspended sediment flux is significantly lowered by the construction of dams and reservoirs along the river course.
35	Kar et al 2008	Study on 96 water samples of river ganga from West Bangal during 2004-05 and analysed for pH, EC, Fe, Mn, Zn, Cu, Cd, Cr, Pb, amd Ni. Fe, n, Zn Ni were found in more than 90% samples with significant seasonal variation. The dominance of varius heavy metals in the surface water of the river Ganga followed the sequence; Fe>Mn>Ni>Cr>Pb>Zn>Cu>Cd. A significant positive correlation was exhibited for conductivity with Cd and Cr of water but Mn exhibited a negative correlation with the conductivity.
36	Karet al, 2008	A total of 96 surface water samples collected from river Ganga in West Bengal during 2004-05 was analyzed for pH, EC, Fe, Mn, Zn, Cu, Cd, Cr, Pb and Ni. Overall seasonal variation was significant for Fe, Mn, Cd and Cr. All in all, the dominance of various heavy metals in the surface water of the river Ganga followed the sequence: Fe > Mn > Ni > Cr > Pb > Zn > Cu > Cd. A significant positive correlation was exhibited for conductivity with Cd and Cr of water but

		Mn exhibited a negative correlation with conductivity.
37	Jain et al 2008	Fractionation of metal ions has been carried out with the objective to determine the eco-toxic potential of metal ions. Although, in most cases (except iron) the average trace/heavy metal concentrations in sediments were higher than the standard shale values, the risk assessment code as applied to the present study reveals that only about 1–3% of manganese, <1% of copper, 16–19% of nickel, 4–20% of chromium, 1–4% of lead, 8–13% of cadmium and 1–3% of zinc exist in exchangeable fraction and therefore falls under low to medium risk category. According to the Geo-accumulation Index (GAI), cadmium shows high accumulation in the river sediments, rest of other metals are under unpolluted to moderately polluted class.
38	Purshothaman et al 2008	In lake eutrophication studies, it is always essential to estimate various phosphorous fractions in order to understand the bioavailability of phosphorous. In the present study, phosphorous in various chemical fractions of sediments from the Nainital Lake was determined to ascertain abundance of phosphorous as inorganic, organic, nonapatite inorganic or as apatite phosphorous fraction. The results show, apatite phosphorous to be the dominant form of phosphorous in the Nainital lake sediments accounting for >50% of the total phosphorous. Usage of the Visual Minteq data analysis software of water composition also indicates higher concentrations of orthophosphate.
39	Singh et al 2008	The present paper shows with study of seasonal variations in physical- chemical parameters of Yamuna river (Proposed Lakhwar hydropower project study site) Deheradun. The higher concentration of some parameters is probably due to

		road construction near by the river as a large amount of silt and rock salt (applied to road) generated due to road construction is washed to the nearby river water. The maximum EC level has been recorded during rainy season because the rainwater carried wastewater from various sources. The pH and hardness levels indicate the moderate quality of water. The average value of DO and COD levels indicate the absence of organic pollution sources. Thus present study concludes that river water was not polluted, all results are within permissible limit when compared with National River water quality standards and Bureau of Indian Standards (BIS).
40	Kaushik et al 2009	Concentration of Heavy Metals (Cd, Cr, Fe, Ni) in water, plants and sediments of river Yamuna flowing in Haryana through Delhi are reported here selecting 14 stations covering the upstream and downstream sites of major industrial complexes of the State. Some important characteristics of river water and sediments (pH, EC, Cl^-, SO3, and PO4 in water and sediments, COD of water and organic matter content of sediments) were also analyzed and inter-relationships of all these parameters with heavy metal concentration in different compartments were examined. Concentrations of these metals in river water are generally high exceeding the standard maximum permissible limits prescribed for drinking water, particularly in the downstream sites.
41	Kumar and Bahadur, 2009	Water of River Kosi in stretch of 35 Kms at Rampur was studied for pollution by determining various water quality parameters, for all three seasons viz. winter, summer and rainy season. The river is subjected to severe domestic and

		industrial pollution at Kashipur (U.A). This polluted water is carried down stream to Rampur (U.P.). The pH range is 7.3 to 7.9.The organic pollution is mild as indicated by DO (6.2-7.5 mg/l) and BOD (5.0-6.0 mg/l). But the highest value of COD ranging between 25.0 mg/l to as high as 40.0 mg/l, indicates industrial pollution. To monitor the water quality samples from six stations were collected monthly. In this paper the results of one year study are presented.
42	Pandey et al 2010	The data revealed that the mid-stream water of river Ganga at Varanasi is invariably contaminated by heavy metals. Highest concentrations of Cd, Cr, Cu, Ni and Pb were recorded during winter and that of Zn during summer season. The overall concentration of heavy metals in water showed the trend : Zn > Ni > Cr > Pb > Cu > Cd. Concentrations of all the heavy metals were high in down - stream sampling stations. Correlation analysis showed that heavy metal concentration in mid-stream water had significant positive relationship with rate of atmospheric deposition at respective sites. Although the concentrations of these metals in water remained below the permissible limits of Indian standards for drinking water, levels of Cd, Ni and Pb at three stations, were above the internationally recommended (WHO) maximum admissible concentrations (MAC).
43	Pankaj et al 2010	The effect of mixed effluents of paper and sugar industries in river Bhegul passing through Bareilly district of Uttar Pradesh was studied on Physico-chemical properties of water. The physico-chemical parameter studied were Temperature, pH, Total solids, Total suspended solids, Total dissolved solids, Dissolve oxygen (D.O.), Biological oxygen demand (BOD), Chemical oxygen

		demand (COD), Calcium, Hardness, Alkalinity, Chlorides. The results obtained showed fluctuations in these parameter's which gave an idea about the intensity of pollution caused by these industrial effluents.
44	Sekabira et al 2010	The purpose of this study was to investigate heavy metal contaminants in the Nakivubo Stream water in Kampala, Uganda. Water samples Nakivubo Channelized Stream, tributaries and industrial effluents that drain into the stream were collected and analysed for the total elemental concentration using flame atomic absorption spectrophotometer. The results showed that: 1) the wastewater was highly enriched with lead and manganese above the maximum permissible limit; 2) the levels of dissolved oxygen were below the maximum permissible limit, while the biological oxygen demand was above the maximum permissible limit.
45	Singh et al 2010	Assessment of physico-chemical parameters were carries out during April 2008 to March 2009 from four rivers namely the Imphal, Iril, Thoubal and Manipur located in Manipur, India. The results indicated that most of the physico-chemical parameters from Manipur river system were within WHO limits for drinking water and, therefore, may be suitable for domestic purpose.
46	Md. Wasim et al 2010	A study was conducted during November 2005-October 2006 to evaluate the surface water quality of river Ganga around Kolkata for various physico-chemical parameters and heavy metals at four different locations. In the study interstingly Cr was not detected in any of the 96 sample and metals exhibited no significant variation with respect to sampling location as well as discharge points. However

		concentration of metals varied seasonally with higher values in rainy season and lower in winter season.

2.2 FATE AND EFFECTS ON THE ENVIRONMENT

The pollutants discharged from the pulp and paper industry affect all aspects of the environment such as water, air and land. Fate of the resin acid in the secondary treatment system was discussed (Makris and Banerjee, 2002) and various authors at different times reported the appearance of toxic effects on various fish species due to exposure of pulp and paper mill effluents. Many authors reported the presence of toxic pollutants in fish or toxic effects on fish such as respiratory stress, mixed function oxygenase activity, toxicity and mutagenicity, liver damage, or genotoxic effects, and lethal effects on the fishes exposed to pulp and paper mill wastewaters (Owens et al 1994, Vass et al 1996). Baruah in 1997 reported on serious concerns related to the surface plankton population change in Elengabeel's wetland ecosystem in India due to untreated paper mill effluent discharge into the system. Possibility of the sub-lethal effects to the aquatic organisms in the Dong Nai River in Vietnam was reported due to the effluents discharged from a pulp and paper mill (Yen etal, 1996). Effects of the treated pulp mill effluent on irrigated soil in northern Arizona showed serious soil chemistry and toxic effects of pulp and paper mill effluent (treated) was investigated in paddy field of Asam, India (Dutta, 1999). High loads of organic pollutants derived from the paper mill wastewater was also reported in Tamilnadu, and Punjab, India (Gupta, 1997) as well as high level of coliform bacteria in the effluent too (Singh et al 1996).

2.3 WASTE WATER TREATMENT OF PULP AND PAPER INDUSTRY

There are conventional processes for detection of pollutants by analytical methods and treatment which is based on the quantity of pollutant. Conventional treatment units involved chemical neutralization followed by the biological treatment which lead to removal of organic complex contaminants from effluent and transferred into sludge thus shifting pollutants from one phase to another. However, the pollutants still persists in the environment. Newer technological applications such as membrane separation, tertiary biofiltration, ozonation treatment, wet oxidation treatment, fixed bed biofilm processing, nitrogen fixation, and aerobic biotechnological treatment methods will increase in demand as antiquated pulp and paper mills are upgraded to meet current treatment standards (Milton, 2008). A comparison of all treatment process concluded that combination of aerobic and anaerobic is effective and efficient process in removal of soluble biodegradable organic pollutants (Thompson et al, 2001) while color can be removed efficiently by fungal treatment, coagulation, chemical oxidation and ozonation while chlorinated phenolic compounds and adsorable organic halides (AOx) can be effectively reduced by adsorption, ozonation, and membrane filtration techniques (Pokhreal et al, 2004). A 60% reduction in effluent BOD due to an internal process change in Irving Pulp and Paper Limited, Canada was reported (Dube et al, 2000).

2.3.1 Physicochemical treatment

Physicochemical treatment processes include removal of suspended solids, colloidal particles, floating matters, colors, and toxic compounds by sedimentation, flotation, screening, adsorption, coagulation, oxidation, ozonation, electrolysis, reverse osmosis, ultra-filtration, and nano-filtration technologies.

Sedimentation/flotation

Suspended matters present in the pulp and paper wastewater are comprised primarily of bark particles, fiber, fiber debris, and filler and coating materials. Sedimentation was the preferred option within the paper mills in the UK, and contributed to more than 80% removal/settling of the suspended solids on an average (Thompson et al 2001), with design value of the primary clarifier 70–80% in average (Rajvaidya and Markandey, 1998) and at appropriate pH range (Azevedo, 1999).

Coagulation and precipitation

Coagulation and flocculation is normally employed in the tertiary treatment in the case of pulp and paper mill wastewater treatment and not commonly adopted in the primary treatment. A comparative study of horseradish peroxide (chitosan) and other coagulants such as $Al_2(SO_4)_3$, hexamethylene diamine epichlorohydrin polycondensate (HE), polyethyleneimine (PEI), to remove adsorbable organic halides (AOX), total organic carbon (TOC), and color was carried out and the authors indicated that modified chitosan was far more effective in removing these pollutants than other coagulants (Tong et al, 1999; Ganjidoust, 1997). Treatment of foul condensate, defined by phenolic compounds, and toxicity using microtox assay from kraft pulping by horseradish peroxide and H_2O_2 resulting in a total phenol reduction below 1 mg/l and toxicity (microtox assay) reduction by 46%. Treatment of black liquor was carried out by precipitation with $CaSO_4$-$2H_2O$ in the presence of CO_2 (Sheela nd Distidar, 1989) with removal of dissolved solids was reported to be 63%. However, use of coagulants such as polyethylene oxide (PEO), worsened the settlability and increased COD levels, turbidity, and suspended solids of the treated effluent when the dose was between 25 and 250 ppm (Wang and Pan 1999). Coagulation with aluminum sulfate or modified adsorbents was the best option for color removal from the sulfate and sulfite wood pulp and paper industry (Chernoberezhskii, 1994).

Adsorption

A 90% removal of color, COD, DOC, and AOX from bleached wastewater by the adsorption process, using activated coke as an adsorbent was reported (Shawwa, 2001). It was observed that the wastewater produced by the Union

Camp Facility at Franklin, VA, can be treated by activated carbon and ion exchange to reduce color and chloride to levels acceptable for reuse (Sullivan, 1986). Lignin removal efficiency of the pulp and paper mill effluent was found to be increased with blast furnace dust (80.4%) and slag (61%) by the adsorption mechanism (Das and Patnaik, 2000).

Chemical oxidation

Photocatalytic oxidation of kraft pulp bleaching wastewater showed that the removal of pollutants is largely depend on the concentration of COD and chloride below a certain level (Balcioglu and Ferhan, 2000). Combination of Fenton and photo-fenton reactions proved to be highly effective for the treatment of bleaching kraft mill effluent (Perez et al, 2002) while the improvement in biodegradability of an effluent from 30% to 70% was observed by applying wet oxidation method (Verenich et al, 2000). Oxidation of total reduced sulfur (TRS) results in odor free products by catalytically enhanced oxidation (Dufresne et al, 2000).

Membrane filtration

Removal of color from pulp and paper mill effluent was reported by membrane filtration technology with a finding that composition of the color had a significant influence on the performance of the membrane (Jokela and Keskitalo, 1996)˙ Efficiency of (1) ultra-filtration and (2) ultra-filtration associated with dissolved air flotation was studied and it was observed that 54%, 88%, 100% removal of TOC, color, and SS, respectively by ultra-filtration alone and ultra-filtration associated with dissolved air flotation resulted in 65%, 90% and 100% removal of TOC, color, and SS, respectively (De Pinho et al, 2001). Reverse osmosis is also a modern technology for waste water purification. For pulp and paper mill effluent application of reverse osmosis resulted in 88% and 89% removal of BOD, and COD, respectively and membrane filtration (MF), and granular membrane filtration (GMF) were also found suitable for removing heavy metals from the pulp and paper mill wastewaters (Merrill et al, 2001).

Ozonation

A substantial removal of COD, TOC, and toxicity from pulp mill effluent and increased biodegradability of the effluent were achieved after treatment with ozone (Yeber et al, 1999). Ozone treatment also resulted in 90% removal of ethylenediaminetetraacetic acid (EDTA) and 65% removal of COD from pulp mill effluent (Korhonen and Tuhkanen, 2000). A 12% reduction of total organic carbon, total phenols reduced to 70%, and effluent colors to 35% of bleached pulp mill effluent after 60 min of ozonation (Freire et al, 2000). Removal of lipophilic wood extractives from TMP wastewater by ozonation was also observed and it was found that a high dosage of ozone (100–300 mg/dm^3) was required to remove 50% of lipophilic wood extractives. Korhonen and Tuhkanen, 2000 reported that Ozone doses of 0.2 mgO_3/initial mg COD eliminated over 90% resin acid from waste waterOzone retention time of 15 minutes with higher doe resulted in 95–97% color removal (Sevimli et al, 2002), which further enhanced by combine application of ozonation and adsorption (Kallas and Munter, 1994).

2.3.2 Biological treatment

Aerobic treatment

<u>Activated sludge process</u>**.** Efficient removal of color, BOD, COD, phenolics, and sulfide by microorganisms such as *Pseudomonas putida, Citrobacter sp*., and *Enterobacter sp*. in the activated sludge process was observed (Chandra, 2001). Removal of chlorinated phenols, 1,1-dichlorodimethyl sulfone (DDS), and chlorinated acetic acids, and AOX removal (Demirbas et al, 1994) took place in an oxygen activated sludge effluent treatment plant. Removal of BOD_7 up to 90%, COD up to 70%, AOX up to 40–60% with average value of 46% (Bryant et al 1992), and chlorinated phenols removal up to 95% was performed under the activated sludge process (Junna and Ruonala, 1991). A minimum 2000–2500 mg/l of mixed liquor suspended solids (MLSS) and an aeration time of 6–8 hr were required to remove 83–88% of BOD (Raghuveer and Sastry, 1991).

Aerated lagoons. The effect of simple mixing in an aerated lagoon was resulted in 15–46% removal of overall pollution load with 67% removal of ammonia from black liquor at temperature of 22–35^{0}C, and pH near 7.3 (Demirbas et al, 1994). COD removal of 30–40% in a full scale lagoon and 60–70% in a pilot-scale plant was observed in a study during 1997 (Welander et al, 1999). An oxidation pond is an effective treatment option which removes more than 50% chemical compounds from the effluent (Achoka, 2002).

Aerobic biological reactors. Many authors have reported high removals of organic pollutants of kraft mill wastewater by sequencing batch reactor (SBR) treatment (Franta et al, 1994). A 100% removal of methanol and 90% removal of COD by SBR were reported (Ried and Simon, 2000). Substantial removal of COD, TOC, BOD (Magnus et al, 2000a), lignin and resin acids (Magnus et al, 2000b) of TMP wastewater using high rate compact reactors (HCRs) at a retention time of 1.5 h had been reported. However, 93% and 65% removal of BOD and COD, respectively by a biological compact reactor was also studied by the same author (Magnus et al 2000c). A biofilter can achieved 76%, 62%, 81%, and 48% removal of BOD, COD, SS, and AOX, respectively (Rovel et al 1994).

Anaerobic treatment

Pretreatment of the kraft mill black liquor was investigated and it was found that continuous anaerobic treatment of wastewater contaminated with black liquor was feasible at low to medium loading rates, with a total COD removal of 48–80% and biodegradable COD reduction of 87–96% (Poggi-Varaldo et al, 1996). Chlorine bleaching effluents were not found suitable for anaerobic treatment due to their low biodegradability and presence of toxic substances that affects methanogens (Rajeshwari et al, 2000). A new treatment technology consisted of three steps: (1) stripping of sulfides and other volatile components from condensate; (2) regenerative thermal oxidation of stripper off gases; (3) adsorption of sulfur oxide to treat foul condensate (sulfide) from the black liquor was developed for treatment of the paper mill effluent (Sandquist and Sandstrom, 2000) where removal efficiency for foul condensate was reported to be more than 99% at a pH of 4 and removal of methanol was 90% at a low liquid/gas ratio. Perez et al, 2002 evaluated two anaerobic systems (anaerobic filters and fluidized bed) in laboratory-scale reactors and reported that 81.5% organic removal efficiency was obtained in the case of fluidized bed with porous packing and 50% removal was obtained in the case of anaerobic filters on corrugated plastic tubes. A 50% reduction of BOD of debarking wastewater was observed by using a fluidized bed reactor (Rajeshwariet al 2000)

Fungal treatment

Pencillium species of fungi was isolated (Taseli and Gokcay, 1999) which was able to remove 50% of the AOX, and color from the soft-wood bleachery effluents in a contact time of 2 days. Substantial reduction of color and COD was observed by the use of white rot fungi *T. versicolor and P. chrysosporium*. White-rot fungi *P. chrysosporium* in combination with other white-rot fungi (*P. sanguineus, P. ostreatus and H. annosum*) and with the use of the surfactants were able to remove color, COD, and lignin content (Saxena and Gupta, 1998). Lignin, BOD, COD and color removal were achieved to the extent of 77%, 76.8%, 60%, and 80% respectively, by the fungal specie *Pleurotus ostreatus* (Choudhury et al 1998).

2.3.3 Integrated treatment processes

An integrated or hybrid system is designed to take advantage of unique features of two or more processes. A combination of coagulation and wet oxidation removed 51% of COD and 83% of color and 75% of lignin (Verenich et al, 2000). A combination of ozone and biofilm reactor removed 80% COD (Helble et al, 1999). It was also studied that post treatment methods such as electrolysis or ozonation are very much fruitful in reduction of COD, and NH_4^+–N concentration to the permitted level (Athanasopoulos, 2001). Efficient degradation of lignin by using a combined treatment of ozone and activated sludge process was studied (Nakamura, 1997). However, a combination of dissolved air flotation and chemical precipitation removed 93% SS, 50% BOD_7, 57% COD, 92% phosphorus, and 52% nitrogen (Jokela and Keskitalo, 1996). A new concept of Kaldnes (anaerobic followed by aerobic) moving bed biofilm reactor at 55^0C removed about 60% of soluble COD from TMP whitewater (Jahren and Oedegaard, 1999). Badar, 1996 suggested a number of methods to improve the integrated paper mill wastewater effluent treatment: (1) increasing the capacity of the aeration basin; (2) installing an extra dissolved air flotation clarifier; (3) adding chlorine gas to improve bulking of sludge problem and (4) injecting oxygen to treat BOD during heavy rain and flooded conditions.

2.4 DECENTRALIZED DOMESTIC WASTE WATER TREATMENT

Centralized wastewater collection and treatment systems are costly to build and operate, especially in areas with low population densities and dispersed households. Developing countries lack both funding to construct centralized facilities and technical expertise to manage and operate them. Alternatively, decentralized approach for wastewater treatment which employs a combination of onsite and/or cluster systems is gaining more attention. Most common decentralized treatment and disposal methods are as follows:

2.4.1 Primary treatment methods

There are several onsite wastewater treatment systems which if designed, constructed, operated and maintained properly will provide adequate service and health benefits. The simple septic tank system is the most commonly known primary treatment method for onsite wastewater treatment because of its considerable advantages. Septic tanks remove most settleable solids and function as an anaerobic bioreactor that promotes partial digestion of organic matter. Their main cause of failure is the unsuitability of the soil and the site characteristics (Les and Ashantha, 2003). The Imhoff tank is another primary treatment method that can accommodate higher flow rates than the septic tank, but it is less common. Both systems are inexpensive and simple to operate and maintain. Yet, sludge may cause an odor problem if kept untreated for a long time. The conventional onsite wastewater treatment systems are not effective in removing nitrate and phosphorus compounds and reducing pathogenic organisms. As such, these systems can be used prior to further treatment and disposal. The simple septic tank system could be modified to provide advanced primary treatment of wastewater. The result of the modification would be a septic tank with an effluent filter vault or a septic tank with attached growth. The filter is the additional component for the former septic tank. This filter prevents some solids from entering the effluent and consequently clogging the treatment system as a whole (USEPA, 2002). As for the latter, it is mainly an aerobic system used where the standard anaerobic septic tanks are not a good option. They are primarily used in places where the soil is poor, the groundwater is high, the land available is small or the site is sensitive.

2.4.2 Secondary treatment methods

Considering that sand is the most common and available media for filters, sometimes media filter is equivalent to sand filter. Generally, in areas with deep, permeable soils, septic tank–soil absorption systems can be used. On the other hand, in areas with shallow, very slowly permeable or highly permeable soils more complicated onsite systems will be required.

2.4.3 Treatment/disposal methods

Disposal methods can be simple disposal methods such as the evaporation and evapotranspiration, surface water discharge and reuse. They can also be treatment and disposal methods concurrently such as the subsurface wastewater infiltration, the land application and the constructed wetlands. The various treatment/ disposal methods provide additional treatment to the wastewater before the final disposal. Given the suitable site conditions, subsurface soil absorption is usually the best method of wastewater disposal for single dwellings because of its simplicity, stability and low cost. There are several types of subsurface soil absorption systems (USEPA, 2002). Trenches and beds, seepage pits, mounds, and fills are all covered excavations filled with porous media with a means for introducing and distributing the wastewater throughout the system (USEPA, 2004). Subsurface wastewater infiltration systems may be the best alternative for sites with appropriate soil conditions, groundwater characteristics, slopes and other features. The trenches and beds can operate effectively in almost all climates, do not need electricity for operation and are less costly than the other systems of subsurface wastewater infiltration. However, they can't be used in areas with highly permeable soil. The seepage pits can be used where the water table is too low and the land is not readily available. While the mound system performs well in areas with high water table, very shallow soils, and porous or karstic bedrock, the fill system is effective with different types of soil, bedrock and water table (Garcia et al., 2001; USEAP, 2005). The land treatment systems utilize natural physical, chemical and biological processes within the plant-soil-water matrix to achieve a designed degree of treatment (Crites and Tchobanoglous, 1998). Such systems are simple, inexpensive and reliable. Their pollutant removal level is high and the nutrients are maintained in the soil. Dry sanitation systems that do not use water for the treatment and transport of human excreta are new emerging technologies which will increase with repeated successful experiences of the system. Their main advantages are water resources conservation and pollution prevention of water bodies. The most common type of dry sanitation is referred to as the composting toilet. There is substantial controversy with regard to the evidence of establishing the safety and practicability of dry sanitation with reuse as an everyday practice. As such, it is very crucial to identify under what circumstances dry sanitation technologies are functioning safely and effectively in communities on a long-term basis (Peasy, 2000).

CHAPTER-3 MATERIAL AND METHOD

Present study is carried out in the state of Uttarakhand, nourished by many important rivers of India including river Ganga and Yamuna. The State of Uttarakhand borders Tibet on north, Nepal on east, and the states of Himachal Pradesh and Uttar Pradesh in west and south respectively. Uttarakhand lies between geo-coordinates from $30^0$19'48" N to $78^0$3'36" E. Uttarakhand has geographical area of 53566 Sq Km. Out of the total area, about 85% is hilly/forest/glacier area and remaining 15% area is burdened with most of the commercial activities. The whole state of Uttarakhand is divided into two geographical areas namely Garhwal and Kumaon area. Garhwal area is nourished by river Ganga, Yamuna and Tons, while the river Kosi, Ramganga, Gola etc. are flowing through Kumaon area. Almost all the water bodies of Kumaon region, presented in this paper, are of non-glacier origin and mainly seasonal rivers. This study is carried out with an objective to access water quality of Himalayan rivers flowing trough Uttarakhand which carries industrial and domestic effluent.

All the rivers and lakes of the study area were grouped into four sectors i) River Ganga System having 15 sampling/monitoring stations, ii) River Yamuna System having 05 monitoring/sampling stations (i and ii are of Garhwal Region), iii) Ram Ganga River System having 08 sampling/monitoring station and iv) two monitoring stations at Naini Lake (iii and iv are of Kumaon region) making a total of 30 sites. Sampling locations and site characteristics are given in Table-3.1. The locations were selected on upstream and downstream of major urban centers; and before and after confluence of tributaries with the rivers. Site locations are presented in figure-3.1. Samples were collected during winter

(January 2010), spring, (April 2010), monsoon/ summer (July 2010) and autumn (October 2010).

Table:-3.1 Sampling Locations and site characteristics

Sampling Point	Location	Altitude (mt)	Geographical Position	Main source of Water Pollution
River Ganga System				
G-1	River Bhagirati Gangotri	3048	30° 59' 0" N 78° 56' 0" E	Origin of river Bhagirati, Clean water.
G-2	River Alaknanda B/c Nandpryag	1358	30.33°N 79.33°E	Sewage and Muck of H.E. projects from Chamoli
G-3	River Mandakani B/c Nanpryag	1358	30.33°N 79.33°E	Sewage and Muck of H.E. projects from Nand Pryag
G-4	River Alaknanda A/c Nandpryag	914	30.33°N 79.33°E	Sewage
G-5	River Alaknanda B/c Karanpryag	1450	30°15'41"N 79°13'10"E	Sewage from Karanpryag
G-6	River Pinder B/c Karanpryag	1450	30°15'41"N 79°13'10"E	Sewage from Karanpryag
G-7	River Alaknanda A/c Karanpryag	1450	30°15'41"N 79°13'10"E	Sewage
G-8	River Bhagirathi Utterkashi Down stream	1165	30°43'40"N 78°26'8"E	Sewage and Muck of H.E. projects from Utterkashi Town
G-9	River Alaknanda Rudrapryag U/s	895	30°19'11"N 78°59'57"E	Sewage Muck of H.E. projects
G-10	River Alaknanda Rudrapryag D/s	895	30°19'11"N 78°59'57"E	Sewage Muck of H.E. projects
G-11	River Alaknanda B/c Deopryag	472	30°9'2"N 78°35'45"E	Sewage Muck of H.E. projects
G-12	River Bhagirati B/c Deopryag	472	30°9'2"N 78°35'45"E	Sewage Muck of H.E. projects
G-13	River Ganga A/c Deopryag	472	30°9'2"N 78°35'45"E	Sewage Muck of H.E. projects
G-14	River Ganga Rishikesh up Stream	532	30°6'27"N 78°16'49"E	Sewage and some Industrial Sources
G-15	River Ganga Haridwar Down Stream	250	29°56'26"N 78°8'42"E	Sewage and Industrial Sources
River Yamuna System				
Y-1	River Yamuna	3293	31°1′0.12″N	Origin of river Yamuna

	Yamunotri		78°27′0″E	
Y-2	River Yamuna Dakpathar Up stream	490	30°30'15"N 77°47'41"E	Sewage Muck of H.E. projects
Y-3	River Yamuna Vikas Nagar Down Stream	430	30°28'12"N 77°46'28"E	Sewage
Y-4	River Tons Down Stream Dehradun	399	30°20'8"N 77°57'25"E	Sewage, Dairy etc.
Y-5	River Tons before confluence in river Yamuna	427	30°27'22"N 77°44'11"E	Sewage, industrial
Rivers of Kumaon Region				
K-1	River Gola (U/S Haldwani)	423	29° 12' 42" N, 79° 31' 8" E	Sewage
K-2	River Gola (D/S Haldwani -Lalkua)	423	29.08°N 79.52°E	Industrial Sources, Sewage
K-3	River Kosi (U/S Ram Nagar)	1020	29°13′N 78°57′E	Industrial
K-4	River Kosi (at the point entering in U.P.)	260	29°13′N 78°57′E	Industrial
K-5	River Kailash (U/S Sitarganj)	1550	28°55'42"N 79°42'10"E	Sewage
K-6	River Kailash (D/S Sitarganj)	1550	28°55'42"N 79°42'10"E	Industrial
K-7	River Dhela (Kashipur)	500	29°13'13"N 78°58'17"E	Industrial
K-8	River Bhela (Kashipur)	500	29°13'13"N 78°58'17"E	Industrial
L-1	Naini Lake (Malli Tal)	1938	29°23'9"N 79°30'50"E	Sewage
L-2	Naini Lake (Talli Tal)	1938	29°23'9"N 79°30'50"E	Sewage

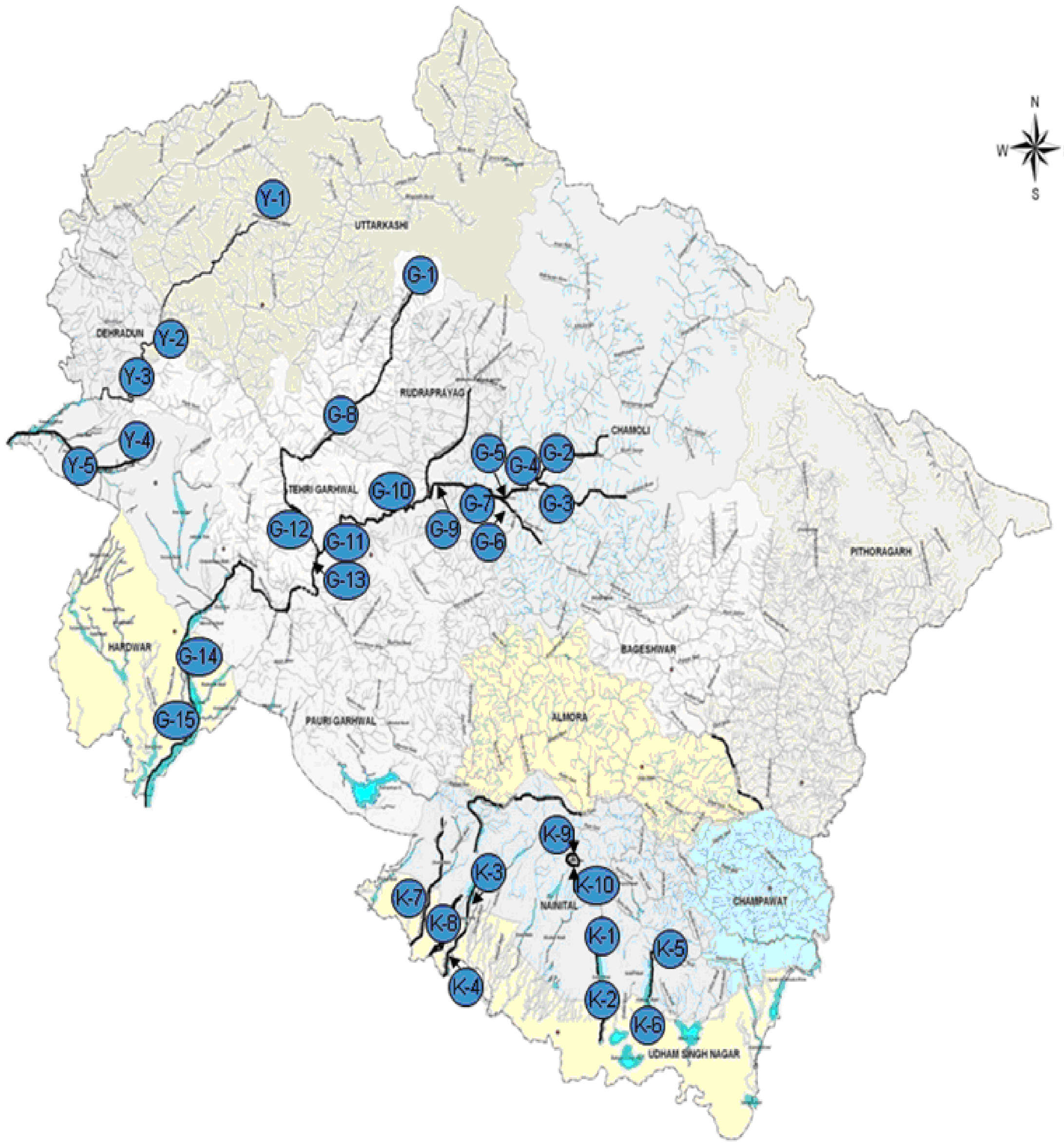


Fig 2.1 Site Locations presenting in a map (not scaled)

Integrated grab samples were collected in high-grade plastic bottles of 2 Liter capacity in triplicate and mixed to get a composite sample. All the sample bottles were stored in ice box till brought to laboratory for analysis. On site analysis of Dissolved oxygen was done gravimetrically; pH, Electrical Conductivity and TDS, was measured by Eventech Cybernetics Model meters. Water samples were preserved at pH < 2 in separate 300 ml plastic bottle by adding concentrated HNO_3 for heavy metal analysis.

Samples were analyzed for phosphate (PO_4) by spectrophotometer; Biological Oxygen Demand (BOD), Total Hardness (TH), Total Alkalinity (TA), Total Suspended Solids (TSS), Chloride (Cl) gravimetrically; Sodium (Na) and Potassium (K) by Flame Photometer. Samples for Pb, Cu, Fe, Zn were analyzed by Atomic Absorption Spectrophotometer (Perkin Elmer A Analyst 300). Detailed analytical procedure is being described below:

3.1 TEMPERATURE

Centigrade calibrated thermometers were used to record the temperature of surface water for measuring water temperature. Thermometer was dipped into water up to a desirable depth for 5-7 minutes and reading was taken. Thermometer should not be taken out of water body while taking reading.

3.2 PH (HYDROGEN ION CONCENTRATION)

Measurement of pH is one of the most important and frequently used tests in water chemistry. pH is the hydrogen ion activity or concentration in the given water sample. pH equal to negatively $\log_{10}$ of hydrogen ion concentration.

$$\mathbf{pH = -\log_{10}(H^+)}$$

pH as define by Sorenson (1909) is $-\log_{10}(H^+)$; it is the "intensity" factor of acidity. pH of water sample was measured by the use of pH strips, but the accurate method is the electrometric method. The sample was analyzed with the help of electronic digital pH meter consisting of a reference and indicator electrode.

Procedure: Calibrate the electrode system against standard buffer solution of known pH. Rinse the electrode using distilled water now dip the electrode in sample water and note the reading on digital screen.

3.3 TOTAL SUSPENDED SOLIDS

Solids refer to matter suspended or dissolved in water or wastewater. Solid may affect water or effluent quality adversely in a number of ways.

Total suspended solid is a term applied to the material residue left in a vessel after filtration of a sample and its subsequent drying in an even at a defined temperature.

Procedure: A 50 ml washed and dried beaker was taken. A filter paper (Whatman No 42 has been taken and weight. 20 ml of unfiltered sample was taken in that beaker and sample was filtered through Whatman NO 42 filter paper. The final weight of the Filter paper was taken after drying of sample.

Calculation

$$\text{Total Suspended Solid, mg/l} = \frac{A-Bx1000x1000}{V}$$

where

A= Final weight of Filter Paper in gm

B= Initial weight of Filter Paper in gm

V= Volume of sample taken in ml

3.4 DISSOLVED OXYGEN

Dissolved Oxygen (DO) level in natural water and wastewater depend on the physical, chemical and biochemical activities in the water body. The analysis for DO is a key test in water pollution and waste treatment process control.

DO is the measure of oxygen concentration present in a given water sample. The concentration of oxygen reflects whether the process undergoing is aerobic or anaerobic.

Principle: The manganous sulphate reacts with the alkali (KOH, NaOH) to form a white precipitate of manganous hydroxide, which in the presence of oxygen, gets oxidized to a brown colour compound. In the strong acis medium manganic ions are reduced by iodide ions which get converted into iodine equivalent to the original concentration of oxygen in the sample. The iodine can be titrated against thiosulphate using starch as an indicator.

Certain oxidizing and reducing materials may effectively interfere with the determination of oxygen by converting iodide ions to iodine or vice-versa. The azide modification removes the interference substance specially nitrite, which is destroyed by sodium azide (NaN_2). That's why azide modification method is used to determine dissolved oxygen instead of Wrinkler's iodometric method.

Procedure: Fill sample water in 300 ml capacity BOD bottle upto the rim and stopper is placed inside water body avoiding any kind of air bubble inside it. Add 2 ml each of $MnSO_4$ and alkaline iodide azide solution using separate pipettes. A precipitate was appeared. The bottle was kept for some time afte mixing thoroughly. At this stage the DO was fixed 2 ml of Concentrated H_2SO_4 was added to dissolve the precipitate by shaking it. The part or whole of the content was titrated against sodium thio-sulphate using starch as an indicator. At end point blue colour changes to colourless.

Calculation: When whole contents have been titrated

$$\text{Dissolved Oxygen, (mg/l)} = \frac{(\text{mlxN}) \text{ of titrant} \times 1000 \times 8}{V_1 - V}$$

When only a part of content has been titrated

$$\text{Dissolved Oxygen, (mg/l)} = \frac{(\text{mlxN}) \text{ of titrant} \times 1000 \times 8}{\frac{V_2(V_1 - V)}{V_1}}$$

Where

V_1 = volume of sample bottle after placing stopper

V_2 = volume of part of the contents titrated

V = Volume of $MnSO_4$ and KI added

3.5 BIOLOGICAL OXYGEN DEMAND

The biological oxygen demand (BOD) determination is an empirical test in which standardized laboratory procedure are used to determine the relative oxygen requirement of waste water effluents, and polluted waters. The test measure the molecular oxygen utilized during a specified incubation period for the biochemical degradation of organic matter (carbonaceous demand) and the oxygen used to oxidize inorganic material such as sulfide and ferrous ions. In other words biological oxygen demands (BOD) represents the amount of oxygen for the microbial decomposition of the organic matter in the water. The BOD procedure, which is used extensively in monitoring water quality and biodegradation of waste material, is designed to determine how much oxygen microorganisms consume during oxidation of the organic matter in the sample.

Principle: The principle of the method involves, measuring the difference of the oxygen concentration between the sample and after incubating it for 5 days at 20^0 C.

Procedure: Samples were collected in two BOD bottles of 300 ml capacity from each site. One set of the bottle were kept in BOD incubator at 20^0 C for 5 days and the DO constant was determined in another set immediately. After the compilation of 5 days incubation, the DO of first set was determined and BOD was calculated by means of given formula.

Calculation:

BOD, mg/l = (D_0-D_5)

Where

D_0 = Initial DO in the sample.

D_5 = DO after 5 days

3.6 TOTAL HARDNESS

Water hardened was understood to be a measure of the capacity of water to precipitate soap. Soap is precipitated chiefly by the calcium and magnesium ions present.

Principle: If a small amount of dye such as Eriochrome black T [EBT] is added to an aqueous solution containing calcium and magnesium ions at a pH of 10.0 ±0.1, the solution becomes wine red. If EDTA is added as atitrant, the calcium and magnesium will be complexed and solution turn from wine red to blue, marking the end point of titration.

Procedure: Take 100 ml of sample in a conical flask and add a pinch of EBT indicator and one ml of buffer solution, the solution turns wine red, titrate it against EDTA until wine red colour change to blue.

Calculation

Hardness (EDTA) as mg $CaCO_3$/L = A x B x 1000/ml of sample

Where:

A= mL titration for sample and

B= mg $CaCO_3$ equivlent to 1.00 mL EDTA titrant.

3.7 TOTAL ALKALINITY

Alkalinity of water is its acid-neutralizing capacity. It is the sum of all the titrable bases.

Principle: Total alkalinity, carbonates and biocarbonates can be estimated by titrating the sample with a strong acid (HCL or H_2SO_4), first to pH 8.3 using phenolphthalein as an indicator and then further to pH between 4.2 and 5.4 with methyl orange.

Procedure: Take 100 ml of sample in a conical flask and add 2 drops of phenolphthalein indicator, if solution remains colourless then phenolphthalein alkalinity (PA) =0 i.e. absent and total alkalinity was determined, if solution turns pink, titrate it against 0.1 N HCL until colour disappears this is phenolphthalein alkalinity (PA). Add 2-3 drops of methyl orange indicator to the sample and titrate against 0.1 N HCL until yellow colour changes to pink at the end point this is total alkalinity (TA).

Calculation:

$$\text{PA as } CaCO_3\text{, mg/l} = \frac{(A \times N) \text{ of HCL} \times 1000 \times 50}{\text{Volume of sample (ml)}}$$

$$\text{TA as } CaCO_3\text{, mg/l} = \frac{(B \times N) \text{ of HCL} \times 1000 \times 50}{\text{Volume of sample (ml)}}$$

where

A = ml of HCL used with only phenolphthalein

B = ml of total HCL used with phenolphthalein and methyl orange

3.8 CHLORIDES

The chloride concentratin is higher in wastewater than in raw water because sodium chloride(NaCl) is common article of diet and passes unchanged through the digestive system.

Principle: Silver nitrate reacts with chloride to form very slightly soluble white precipitate of AgCl. At the end point when all the chlorides get precipitated, free silver ions react with chromate to form silver chromate of reddish brown colour.

Procedure: Take 50 ml of sample in a conical flask and add 2 ml of potassium chromate to it, titrate the solution against silver nitrate until persistent red tinge appears.

Calculation:

$$\textbf{Chloride, mg/l} = \frac{\textbf{(mxN) of } AgNO_3 \textbf{x1000x35.5}}{\textbf{ml of sample}}$$

3.9 PHOSPHATE

Procedure

a. Preliminary sample treatment: to 100 mL sample containing not more than 200 µg P and free from color and turbidity, add 0.05 mL (1 drop) phenolphthalein in dicator. If sample turns pink, add strong acid solution dropwise to discharge the color. If more than 0.25 mL (5 drops) is required, take a smaller sample and dilute to 100 mL with distilled water after first discharging the pink color with acid.

b. Color development: add, with thorough mixing after each addition, 4.0 mL molybdate reagent I and 0.5 mL (10 drops) stannous chloride reagent I. Rate of color development and intensity of color depend on temperature of the final solution, each 1^0C increase producing about 1% increase in color. Hence, hold samples, standards, and reagents within 2^0C of one another and in the temperature range between 20 and 30^0C.

c. Color measurement: After 10 min, but before 12 min, using the same specific interval for all determinations, measure color photometrically at 690 nm and compare with a calibration curve, using a distilled water blank. Light path lengths suitable for various concentration ranges are as follow:

Approximate P Rang Mg/L	Light Path cm
0.3-2	0.5
0.1-1	2
0.007-0.2	10

Calculation:

Measure the intensity of the ample at 690 nm and compare it with standard cure to obtain the concentration of Phosphate.

3.10 SODIUM AND POTASSIUM

Standard solution and Standard Curve

Sodium: Dissolved 2.542 gm NaCl and dilute to 1000 ml with distilled water. 1 ml of this solution is equal to 1 mg of Na. Standard solution of 1.0 to 10.0 has been prepared and analyzed emission for Na at Flame Photometer at 589 nm.

Potassium: Dissolved 1.907 gm KCl and dilute to 1000 ml with distilled water. 1 ml of this solution is equal to 1 mg of Na. Standard solution of 1.0 to 10.0 has been prepared and analyzed emission for Na at Flame Photometer at 766 nm.

Instrument operation

Adjust slit width and sensitivity, appropriate fuel and air or oxygen pressures, and the steps for warm-up, correcting for interferences and flame background, rinsing of burner, igniting sample, and measuring emission intensity at appropriate wave length.

Calculation

For direct reference to the calibration curve:

Mg Na/L = (mg Na/L in portion) x D

Mg K/L = (mg K/L in portion) x D

Where: D= dilution ratio

3.11 HEAVY METALS

Heavy metals of water samples were analyzed using atomic absorption spectrophotometer (AAS)

Principal of AAS: Atomic absorption spectrophotometer (AAS) uses the hollow cathode lamp (HCL). The hollow cathode lamp gives off light characteristics to the element wavelength being measured. Thus, the light absorbed measures the atomic density. In other words it is based on the measurement of the decrease in light intensity from a source (hollow cathode lamp) when it passes through a vapor layer of the analytic element.

Method of Using AAS: In AAS, a sample is aspired into a flame and automized and a light beam is directed through the flame, into a monochromater and onto a detector that measures the amount of light absorbed by the automized element in the flame. Each metal has its own characteristics wavelength. A source lamp composed of that element is used. The amount of energy of the characteristics wavelength absorbed in the flame is proportional to the concentration of element in the sample.

The instrument was calibrated , for each metal to be detected, with known standard. After calibration and programming, the prepared samples were aspirated to the flame. Zero was set with double distilled water before each determination. Results were displayed in µgm/l from which the actual concentration in water sample was calculated. It was the total content of water sample, which was expressed in mg/l (ppm).

Standard Solution and Standard Curve for Heavy Metals

Copper: dissolve 1.000 g copper metal in 15 mL of 1 + 1 HNO_3 and dilute to 1000 mL with water; 1.00 mL = 1.00 mg Cu.

Iron: Dissolve 1.000 g iron wire in 50 mL of 1+1 HNO_3 and dilute to 1000 mL with water; 1.00 mL = 1.00 mg Fe.

Lead: Dissolve 1.598 g lead nitrate, Pb $(NO_3)_2$, in about 200 mL water, add 1.5 mL conc HNO_3, and dilute to 1000 mL with water; 1.00 mL = 1.00 mg Pb.

Zinc: Dissolve 1.000 g zinc metal in 20 mL 1 + 1 HCL and dilute to 1000 mL with water; 1.00 mL = 1.00 mg Zn.

Analytical Procedure of Heavy Metals

a. Digestion of Samples: Filtered water samples were digested by adding 2 ml HNO3.

b. Instrument operation: heavy Metals are analysed at Atomic Adsorption Spectrophotometer model no Perkin Elmer A Analyst 300. In general, install a hollow cathode lamp for the desired metal in the instrument and roughly set the wavelength h as mentioned in previous section. Turn on instrument, and let instrument warm up until energy source stabilizes. Install suitable burner head and adjust burner head position. Turn on air and adjust flow rate to that specified by manufacturer to give maximum sensitivity for the metal being measured. Turn on acetylene, adjust flow rate to value specified, and ignite flame. Aspirate a standard solution and adjust aspiration rate of the nebulizer to obtain maximum sensitivity. Atomize a standard (usually on near the middle of the linear working range) and adjust burner both up and down and sideways to obtain maximum response. Absorbance is recorded when freshly prepared sample is aspirated and with a new hollow-cathode lamp.

3.12 POLLUTION LOAD ASSESSMENT

Data of pollution load has been complied since Jan 2006 to October 2010 for Kumaon rivers especially river Kosi, river Bhela, river Dhela. These three rivers receives maximum of industrial effluent of Kumaon region. However, in Garhwal region, industrial density w.r.t. volume of discharge is quite minimal as compared to Kumaon region. From the review on pulp and paper industries waste water treatment, it is found that advance technologies such as membrane technology, fungal treatment and Activated sludge with ozonation are helpful in reducing the pollution load very significantly. These technologies were implied in lab to treated effluent of pulp and paper mill after conventional treatment.

For Membrane Treatment: Home Water purifier with membrane is used for passing of effluent of paper industry and analysed for Biochemical oxygen demand.

For Fungal Treatment: Suspension of *Pleurotus ostreatus* is used in effluent and results were analysed for reduction in BOD

For ozonation,: Ozone is applied in ASP of Paper mill and anlysed for reduction in BOD.

CHAPTER-4 RESULT AND DISCUSSION

4.1 PHYSICOCHEMICAL PARAMETERS

Results obtained for Temperature, pH, Dissolved Oxygen, Biological Oxygen Demand, Total Dissolved Solids, Total Suspended Solids, Electrical Conductivity, Sodium, Potassium Chloride and Phosphate are discussed in subsequent sections.

4.1.1 Temperature Temperature data of all water bodies is presented in table 4.1.1 with mean and standard deviation in different river systems in table-4.1.2. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.1.

In River Ganga System Temperature varied from 13.0^{0}C to 24.0^{0}C in all water bodies. Lower temperature was found at higher altitudes and higher temperature was found in the water bodies flowing in plains. Mean values of temperature is found 17.47^{0}C in January 2010; 19.3^{0}C in April 2010; 16.4^{0}C each in July 2010 and October 2010. Mean values of temperature 17.4 ^{0}C are found in river Yamuna System during January 2010 and October 2010, while mean temperature values 18.60^{0}C and 17.4^{0}C are observed in April 2010 and July 2010. Higher mean values of temperature during entire study period are observed in Kumaon rivers which are 20.75^{0}C, 24.13^{0}C, 20.38^{0}C and 21.38^{0}C during January to October 2010 respectively. Slightly lower mean values of temperature are observed in Lake Naini during July 2010. However, during remaining seasons it varies from 20.0^{0}C to 22.0^{0}C. Values of temperature are found higher in Kumaon rivers which may be due to the fact that the Kumaon rivers receives huge load of industrial effluent.

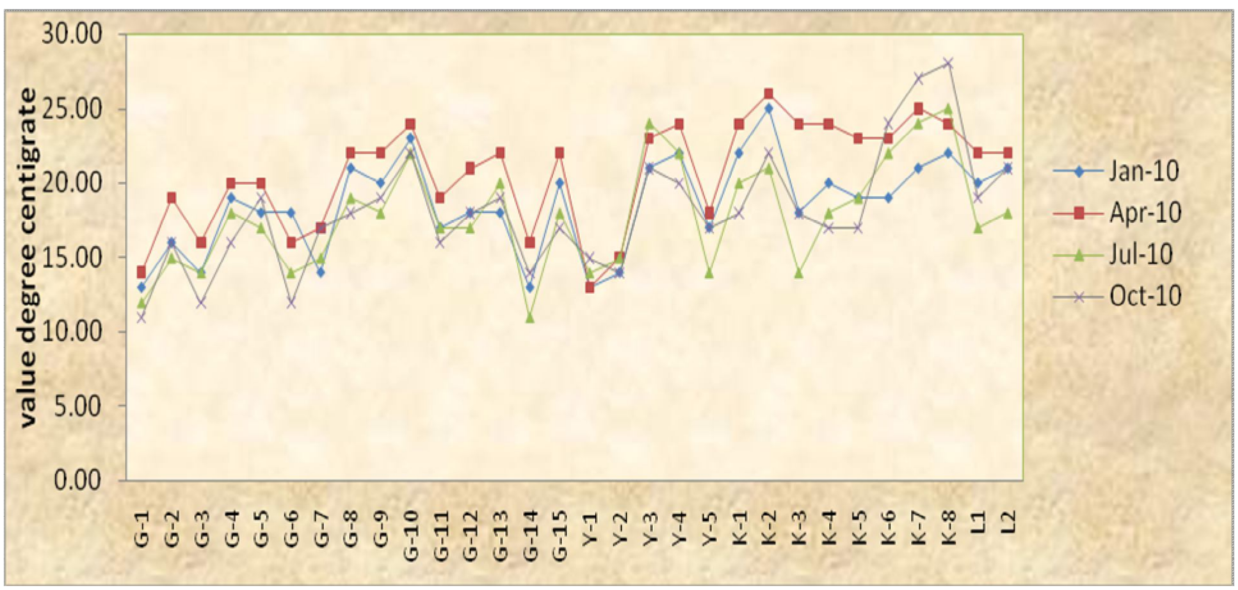
Table 4.1.1 Value of Temperature in ^{0}C in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	13.00	14.00	12.00	11.00
	G-2	16.00	19.00	15.00	16.00
	G-3	14.00	16.00	14.00	12.00
	G-4	19.00	20.00	18.00	16.00
	G-5	18.00	20.00	17.00	19.00
	G-6	18.00	16.00	14.00	12.00
	G-7	14.00	17.00	15.00	17.00
	G-8	21.00	22.00	19.00	18.00
	G-9	20.00	22.00	18.00	19.00
	G-10	23.00	24.00	22.00	22.00
	G-11	17.00	19.00	17.00	16.00
	G-12	18.00	21.00	17.00	18.00
	G-13	18.00	22.00	20.00	19.00
	G-14	13.00	16.00	11.00	14.00
	G-15	20.00	22.00	18.00	17.00
River Yamuna	Y-1	13.00	13.00	14.00	15.00
	Y-2	14.00	15.00	15.00	14.00
	Y-3	21.00	23.00	24.00	21.00
	Y-4	22.00	24.00	22.00	20.00
	Y-5	17.00	18.00	14.00	17.00
Kumaon Rivers	K-1	22.00	24.00	20.00	18.00
	K-2	25.00	26.00	21.00	22.00
	K-3	18.00	24.00	14.00	18.00
	K-4	20.00	24.00	18.00	17.00
	K-5	19.00	23.00	19.00	17.00
	K-6	19.00	23.00	22.00	24.00
	K-7	21.00	25.00	24.00	27.00
	K-8	22.00	24.00	25.00	28.00
Lake Naini	L1	20.00	22.00	17.00	19.00
	L2	21.00	22.00	18.00	21.00

Table 4.1.2 Mean and Standard Deviation of Temperature

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	17.47	19.33	16.47	16.40	17.42
S.D.	3.00	2.94	2.97	3.07	3.15
River Yamuna (n=5x4)					
Mean	17.40	18.60	17.80	17.40	17.80
S.D.	4.04	4.83	4.82	3.05	3.93
Kumaon Rivers (n=8x4)					
Mean	20.75	24.13	20.38	21.38	21.66
S.D.	2.25	0.99	3.50	4.53	3.32
Lake Naini (n=2x4)					
Mean	20.50	22.00	17.50	20.00	20.00
S.D.	0.71	0.00	0.71	1.41	1.85

Fig 4.1.1: Spatial and Temporal Variations of Temperature in Different Water Bodies



4.1.2 pH: pH of all water bodies is presented in table 4.1.3 with mean and standard deviation in different river systems in table-4.1.4. Spatial and temporal variation of pH in different water bodies is presented in figure 4.1.2.

pH vary from 7.3 to 8.9 in river Ganga System with mean value 8.05, 8.15, 7.92 and 7.99 during January 2010 to October 2010 respectively. It vary from 7.8 to 8.9 in river Yamuna system with mean value of 8.24, 7.98.04 and 7.98 from January 2010 to October 2010. Higher variation of pH was found in Kumaon rivers where it vary from 6.60 to 9.10. However, mean values of pH in Kumaon rivers, during all seasons, do not show much variation and lie from 7.18 in April 2010 to 7.69 in January 2010. During April 2010 L1 point of Naini lake shows slightly acidic ph 6.5 while at L-2 point during the same season it is found alkaline with pH value of 8.2. During the remaining seasons no significant variation is observed at both points of the lake. Change in pH values results in change in ionic behavior of the water body and thus results in chelation of the heavy metals along with organic components present in water body. This ultimately results in deterioration of water quality. Most of the wastewater discharging industries are situated in Kumaon region and dispose industrial effluent into rivers and hence the rivers of Kumaon region showed higher fluctuations in pH values.

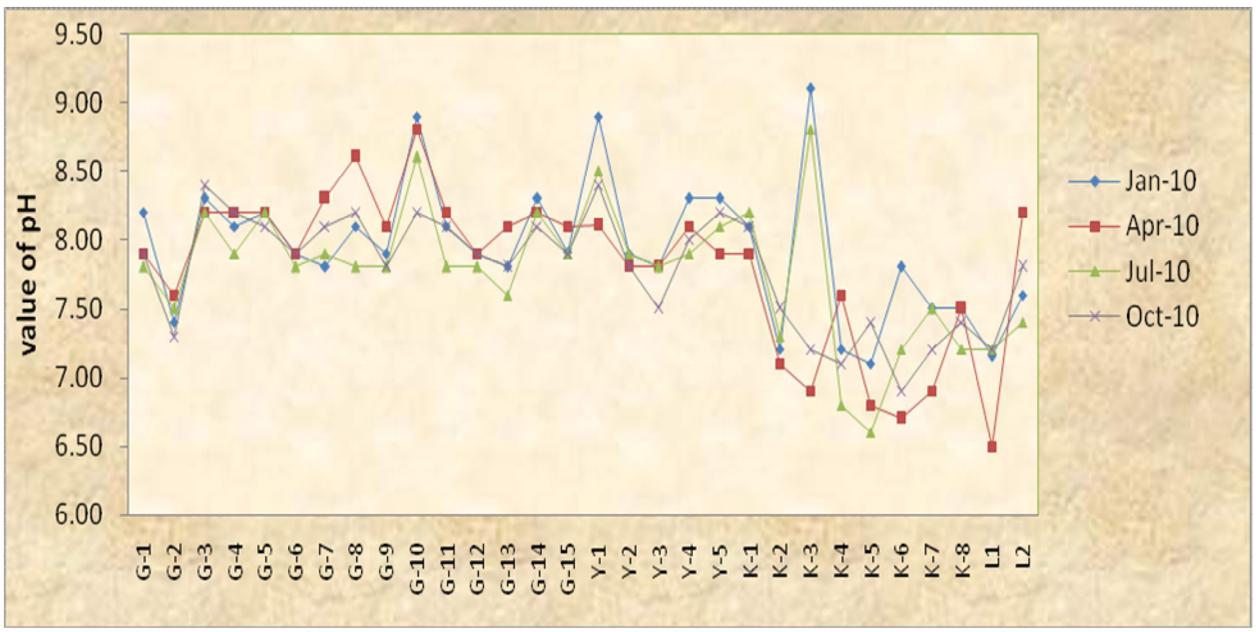
Table 4.1.3 Value of pH in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	8.20	7.90	7.80	7.90
	G-2	7.40	7.60	7.50	7.30
	G-3	8.30	8.20	8.20	8.40
	G-4	8.10	8.20	7.90	8.20
	G-5	8.20	8.20	8.20	8.10
	G-6	7.90	7.90	7.80	7.90
	G-7	7.80	8.30	7.90	8.10
	G-8	8.10	8.60	7.80	8.20
	G-9	7.90	8.10	7.80	7.80
	G-10	8.90	8.80	8.60	8.20
	G-11	8.10	8.20	7.80	8.10
	G-12	7.90	7.90	7.80	7.90
	G-13	7.80	8.10	7.60	7.80
	G-14	8.30	8.20	8.20	8.10
	G-15	7.91	8.10	7.90	7.90
River Yamuna	Y-1	8.90	8.10	8.50	8.40
	Y-2	7.90	7.80	7.90	7.80
	Y-3	7.80	7.80	7.80	7.50
	Y-4	8.30	8.10	7.90	8.00
	Y-5	8.30	7.90	8.10	8.20
Kumaon Rivers	K-1	8.10	7.90	8.20	8.10
	K-2	7.20	7.10	7.30	7.50
	K-3	9.10	6.90	8.80	7.20
	K-4	7.20	7.60	6.80	7.10
	K-5	7.10	6.80	6.60	7.40
	K-6	7.80	6.70	7.20	6.90
	K-7	7.50	6.90	7.50	7.20
	K-8	7.50	7.50	7.20	7.40
Lake Naini	L1	7.15	6.50	7.20	7.20
	L2	7.60	8.20	7.40	7.80

Table 4.1.4 Mean and Standard Deviation of pH

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	8.05	8.15	7.92	7.99	8.03
S.D.	0.33	0.29	0.28	0.26	0.29
River Yamuna (n=5x4)					
Mean	8.24	7.94	8.04	7.98	8.05
S.D.	0.43	0.15	0.28	0.35	0.32
Kumaon Rivers (n=8x4)					
Mean	7.69	7.18	7.45	7.35	7.42
S.D.	0.66	0.44	0.73	0.36	0.57
Lake Naini (n=2x4)					
Mean	7.38	7.35	7.30	7.50	7.38
S.D.	0.32	1.20	0.14	0.42	0.51

Fig 4.1.2: Spatial and Temporal Variations of pH in Different Water Bodies



4.1.3 Dissolved Oxygen (DO) : DO data of all water bodies is presented in table 4.1.5 with mean and standard deviation in different river systems in table-4.1.6. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.3.

Concentration of DO is found varied from 3.6 mgl^{-1} to 10.20 mgl-1 in river Ganga with mean value7.43 mgl^{-1}, 6.94 mgl^{-1}, 6.40 mgl^{-1} and 7.04 mgl^{-1} in January-2010, April-2010, July 2010 and October-2010 respectively. Lower concentration of DO is observed in river Alaknanda at Devprayag due to mass bathing holy offerings and sewage (Semwal and Akolkar, 2006) and Haridwar downstream due to industrial effluent and sewage. It varied from 3.20 mgl-1to 8.90 mgl^{-1} in river Yamuna with lower mean values 5.76 mgl^{-1} in April-2010 and nearly 7.0 mgl^{-1} in remaining seasons. Very low concentration of DO is observed in Kumaon rivers which is found ranging from Not Detectable (ND) to 9.6 mgl^{-1}. Very low mean values are found in April-2010 while during remaining seasons it varied from 3.0 mgl^{-1} to 4.65 mgl^{-1}. In most of Kumaon rivers DO level are found below 3 mgl^{-1} which is an indication that the water is not suitable for fishing, bathing, industrial cooling and recreation purpose (EP Rules, 1986). During January 2010 DO levels are found slightly higher because of low temperature conditions. Concentration of DO is varied from 4.0 $mgl^{-1}$to 8.60mgl^{-1} in Naini lake. Low values of DO indicate poor self sustain system of water bodies with a result of increase in BOD. Higher values of DO in winter season are due to more dissolution of oxygen at lower temperature. Kumaon rivers, due low water flow and high industrial waste water discharge during pre-monsoon season, showed lowered DO and higher BOD.

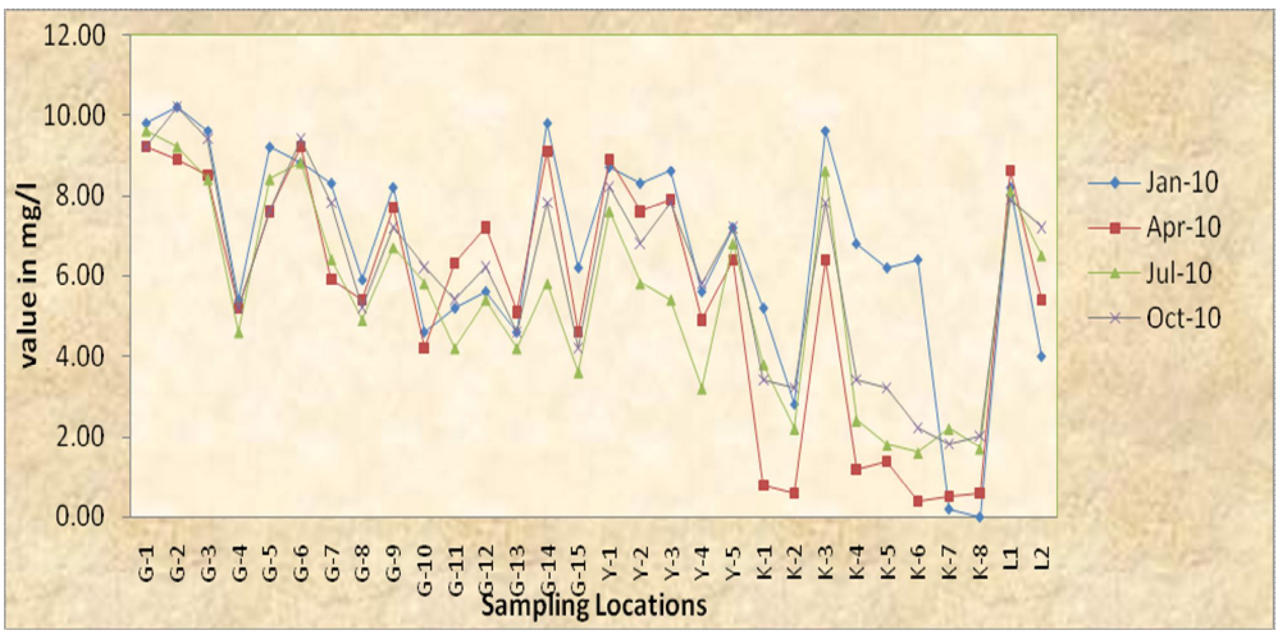
Table 4.1.5 Value of Dissolved Oxygen in mg l^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	9.80	9.20	9.60	9.20
	G-2	10.20	8.90	9.20	10.20
	G-3	9.60	8.50	8.40	9.40
	G-4	5.40	5.20	4.60	5.20
	G-5	9.20	7.60	8.40	7.60
	G-6	8.80	9.20	8.80	9.40
	G-7	8.30	5.90	6.40	7.80
	G-8	5.90	5.40	4.90	5.20
	G-9	8.20	7.70	6.70	7.20
	G-10	4.60	4.20	5.80	6.20
	G-11	5.20	6.30	4.20	5.40
	G-12	5.60	7.20	5.40	6.20
	G-13	4.60	5.10	4.20	4.60
	G-14	9.80	9.10	5.80	7.80
	G-15	6.20	4.60	3.60	4.20
River Yamuna	Y-1	8.70	8.90	7.60	8.20
	Y-2	8.30	7.60	5.80	6.80
	Y-3	8.60	7.90	5.40	7.80
	Y-4	5.60	4.90	3.20	5.80
	Y-5	7.20	6.40	6.80	7.20
Kumaon Rivers	K-1	5.20	0.80	3.80	3.40
	K-2	2.80	0.60	2.20	3.20
	K-3	9.60	6.40	8.60	7.80
	K-4	6.80	1.20	2.40	3.40
	K-5	6.20	1.40	1.80	3.20
	K-6	6.40	0.40	1.60	2.20
	K-7	0.20	0.50	2.20	1.80
	K-8	0.00	0.60	1.70	2.00
Lake Naini	L1	8.20	8.60	8.10	7.90
	L2	4.00	5.40	6.50	7.20

Table 4.1.6 Mean and Standard Deviation of Dissolved Oxygen

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	7.43	6.94	6.40	7.04	6.95
S.D.	2.11	1.80	2.01	1.93	1.95
River Yamuna (n=5x4)					
Mean	7.68	7.14	5.76	7.16	6.94
S.D.	1.31	1.54	1.67	0.93	1.47
Kumaon Rivers (n=8x4)					
Mean	4.65	1.49	3.04	3.38	3.14
S.D.	3.38	2.02	2.35	1.90	2.62
Lake Naini (n=2x4)					
Mean	6.10	7.00	7.30	7.55	6.99
S.D.	2.97	2.26	1.13	0.49	1.60

Fig 4.1.3 Spatial and Temporal Variations of Dissolved Oxygen in Different Water Bodies



3.1.4 Biological Oxygen Demand (BOD): BOD data of all water bodies is presented in table 4.1.7 with mean and standard deviation in different river systems in table-4.1.8. Spatial and temporal variation of temperature in different water bodies is presented in figure 41.4.

Concentration of BOD varied from 2.10 mgl^{-1} at Haridwar up-stream to 14.20 mgl^{-1} at river Bhagirati in Utterkashi in river Ganga System with mean value 6.59 mgl^{-1}, 8.22 mgl^{-1}, 6.69 mgl^{-1} and 6.44 mgl^{-1} in January-2010, April-2010, July 2010 and October-2010 respectively. In most of the sampling stations in river Ganga System BOD values are found higher than 5.0 mgl^{-1} which is an indication that the water is not suitable for drinking, bathing and even for controlled waste disposal (EP Rules, 1986). Concentration of BOD varied from 2.20 mgl^{-1} to 15.90 mgl^{-1} (Downstream Vikas Nagar) in river Yamuna System with higher mean values 8.62 in April-2010 and lower mean value 4.70 mgl^{-1} in October-2010. Very high concentration of DO is observed in Kumaon rivers which is found not de12.8 mgl^{-1} to 140.0 mgl^{-1}. Very high mean values are found in April-2010 while during remaining seasons it varied from nearly 42 mgl^{-1} to 49 mgl^{-1}. BOD levels in all Kumaon rivers are found above 5 mgl^{-1} which shows that the not even a singly studied river of Kumaon region is having water suitable for drinking, bathing, cooling and recreational purpose. (EP Rules, 1986). Concentration of BOD is varied from 2.8 mgl^{-1} to 4.8 mgl^{-1} in Naini lake. All water bodies during the present study show higher values of BOD as compared with the WHO standard for drinking water 1.3 mgl^{-1} (WHO, 1998). This indicates the load of organic pollutants in the river bodies due to increased urbanization and industrialization and shifting of human settlement along the rivers and lakes.

Points of origin of river Ganga and Yamuna are enriched with higher DO and lower BOD. Dissolved Oxygen is also the function of aquatic life and fishes require 5 mgl-1 of DO for survival. Thus river bodies of Uttarakhand except, Kumaon rivers including river Kosi, are suitable for aquatic life. These results are in contradiction with the findings by other authors (Bhargava, 1989; Pandey and Sharma, 1998). In Kashipur area of Kumaon region, there are 24 highly polluting industries out of which 11 units have very poor pollution control facilities (Down to Earth, 2006). DO and BOD in all the water bodies shows negative correlation means higher the BOD lower DO and vice versa.

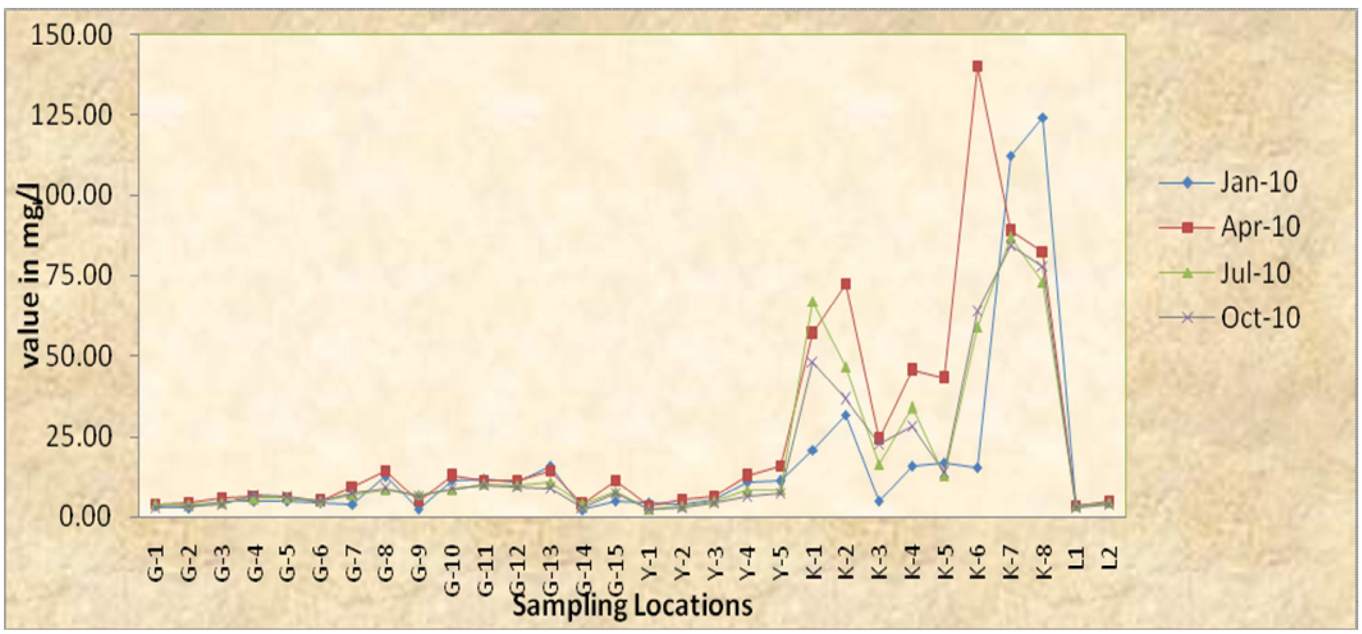
Table 4.1.7 Value of Biological Oxygen Demand in mg l^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	3.20	3.90	3.70	2.80
	G-2	2.60	4.20	3.80	3.20
	G-3	4.60	5.90	4.20	3.80
	G-4	4.90	6.20	5.60	6.80
	G-5	4.70	5.80	5.80	6.20
	G-6	4.20	4.60	4.80	5.00
	G-7	3.70	9.40	6.80	7.40
	G-8	12.60	14.20	8.20	8.60
	G-9	2.20	4.80	6.80	6.40
	G-10	11.20	12.50	8.40	8.80
	G-11	11.80	11.30	10.20	9.60
	G-12	10.60	11.30	9.80	9.40
	G-13	15.60	14.30	10.80	8.60
	G-14	2.10	3.60	3.60	2.80
	G-15	4.80	11.24	7.80	7.20
River Yamuna	Y-1	4.30	3.20	2.20	2.40
	Y-2	3.70	5.20	3.40	3.00
	Y-3	5.20	6.20	4.80	4.40
	Y-4	10.80	12.60	8.40	6.50
	Y-5	11.00	15.90	8.40	7.20
Kumaon Rivers	K-1	20.60	56.80	66.80	48.20
	K-2	31.80	72.60	46.60	36.40
	K-3	4.80	24.00	16.10	22.70
	K-4	15.80	45.30	33.90	28.30
	K-5	16.90	42.90	12.80	13.60
	K-6	15.40	140.00	58.90	63.90
	K-7	112.24	88.60	86.60	84.50
	K-8	124.00	82.30	72.80	77.90
Lake Naini	L1	3.50	3.50	3.20	2.80
	L2	4.20	4.80	4.20	3.80

Table 4.1.8 Mean and Standard Deviation of Biological Oxygen Demand

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	6.59	8.22	6.69	6.44	6.98
S.D.	4.44	3.94	2.45	2.41	3.42
River Yamuna (n=5x4)					
Mean	7.00	8.62	5.44	4.70	6.44
S.D.	3.60	5.38	2.85	2.11	3.72
Kumaon Rivers (n=8x4)					
Mean	42.69	69.06	49.31	46.94	52.00
S.D.	47.24	35.92	26.78	26.23	34.91
Lake Naini (n=2x4)					
Mean	3.85	4.15	3.70	3.30	3.75
S.D.	0.49	0.92	0.71	0.71	0.64

Fig 4.1.4 Spatial and Temporal Variations of Biological Oxygen Demand in Different Water Bodies



4.1.5 Total Suspended Solids (TSS): TSS data of all water bodies is presented in table 4.1.9 with mean and standard deviation in different river systems in table-4.1.10. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.5.

Concentration of TSS is found varied from 24 mgl^{-1} to 534 mgl^{-1} in river Ganga System. Higher values are observed at downstream site of Utterkashi and Haridwar especially during April-2010. It varied from 26 mgl^{-1} to 384 mgl^{-1} in river Yamuna system with higher values during July-2010 at Dehradun downstream site in river Tons where it confluence in river Yamuna. Higher values of TSS are found in Kumaon rivers which varied from quite low concentration at few points to 1864 mgl^{-1}. River Kosi, Dhela, Bhela are showing higher values of TSS. Industrial effluent is the main reason for higher TDS. However, lake Naini shows linear trend of TDS vary from 286 mgl^{-1} to 412 $mgl-^{1}$.

Average mean values of TSS in river Ganga is found118.13 mgl^{-1}, 153.20 mgl^{-1}, 145.53 mgl^{-1}, 146.40 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of TDS is found 79.80 mgl^{-1}, 98.80 mgl^{-1}, 146.40 mgl^{-1} and 135.60 mgl^{-1} during different seasons of year 2010. Overall higher mean values are observed in Kumaon rivers which are 343.00 mgl^{-1}, 464.00 mgl^{-1}, 513.50 mgl^{-1} and 498.00 mgl^{-1} in different seasons respectively. Higher mean values of TSS in lake Naini are observed during April 2010 and July 2010 with lower mean values in October 2010.

4.1.6 Total Dissolved Solids (TDS): TDS data of all water bodies is presented in table 4.1.11 with mean and standard deviation in different river systems in table-4.1.12. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.6.

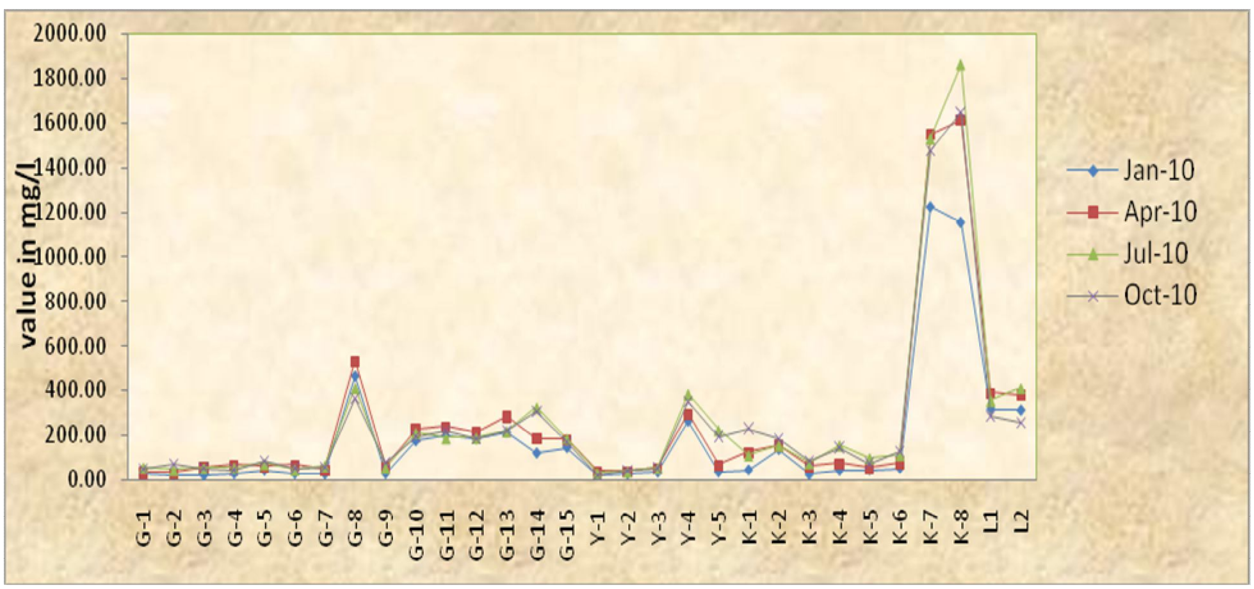
Table 4.1.9 Value of Total Suspended Solids in mg l^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	30.00	35.00	56.00	54.00
	G-2	26.00	32.00	45.00	72.00
	G-3	24.00	56.00	54.00	56.00
	G-4	32.00	68.00	56.00	48.00
	G-5	46.00	62.00	72.00	88.00
	G-6	32.00	66.00	48.00	56.00
	G-7	30.00	45.00	64.00	58.00
	G-8	468.00	534.00	412.00	366.00
	G-9	32.00	62.00	56.00	80.00
	G-10	178.00	228.00	212.00	198.00
	G-11	200.00	240.00	188.00	224.00
	G-12	186.00	214.00	190.00	186.00
	G-13	216.00	286.00	220.00	224.00
	G-14	124.00	186.00	324.00	312.00
	G-15	148.00	184.00	186.00	174.00
River Yamuna	Y-1	26.00	38.00	32.00	24.00
	Y-2	30.00	36.00	38.00	46.00
	Y-3	38.00	54.00	54.00	56.00
	Y-4	266.00	298.00	384.00	354.00
	Y-5	39.00	68.00	224.00	198.00
Kumaon Rivers	K-1	48.00	124.00	112.00	234.00
	K-2	140.00	157.00	156.00	186.00
	K-3	28.00	64.00	78.00	86.00
	K-4	46.00	72.00	156.00	148.00
	K-5	48.00	55.00	98.00	76.00
	K-6	56.00	78.00	114.00	128.00
	K-7	1224.00	1550.00	1530.00	1478.00
	K-8	1154.00	1612.00	1864.00	1648.00
Lake Naini	L1	320.00	390.00	356.00	286.00
	L2	315.00	380.00	412.00	258.00

Table 4.1.10 Mean and Standard Deviation of Total Suspended Solids

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	118.13	153.20	145.53	146.40	140.82
S.D.	121.93	137.01	114.12	102.96	117.35
River Yamuna (n=5x4)					
Mean	79.80	98.80	146.40	135.60	115.15
S.D.	104.23	112.11	154.80	140.01	121.95
Kumaon Rivers (n=8x4)					
Mean	343.00	464.00	513.50	498.00	454.63
S.D.	523.58	690.45	736.38	660.86	628.68
Lake Naini (n=2x4)					
Mean	317.50	385.00	384.00	272.00	339.63
S.D.	3.54	7.07	39.60	19.80	53.72

Fig 4.1.5 Spatial and Temporal Variations of Total Suspended Solids in Different Water Bodies



Concentration of TDS is found varied from 112 mgl^{-1} to 548 mgl^{-1} in river Ganga System. Higher values are observed at downstream site of Utterkashi and Haridwar especially during April-2010. It varied from 112 mgl-1 to 380 mgl^{-1} in river Yamuna system with higher values during July-2010 at Vikas Nagar downstream. Higher values of TDS are found in Kumaon rivers which varied from quite low concentration at few points to 1766 mgl^{-1}. River Kosi, Dhela, Bhela are showing higher values of TDS. Industrial effluent is the main reason for higher TDS. However, lake Naini shows linear trend of TDS vary from 375 mgl^{-1} to 582 mgl^{-1}.

Average mean values of TDS in river Ganga is found 169.8 mgl^{-1}, 268.27 mgl^{-1}, 228.93 mgl^{-1}, 229.07 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of TDS is found 155.40 mgl^{-1}, 197.40 mgl^{-1}, 217.60 mgl^{-1} and 212.0 mgl^{-1} during different seasons of year 2010. Overall higher mean values are observed in Kumaon rivers which are 577.25 mgl^{-1}, 710.5 mgl^{-1}, 828.5 mgl^{-1} and 951.25 mgl^{-1} in different seasons respectively. Higher mean values of TDS in lake Naini are observed during July 2010 with lower mean values in January 2010 i.e. 383.5 mgl^{-1}.

None of the values of TDS in river Ganga System, river Yamuna System and at lake Naini lake during all seasons except Tallital of Naini lake during July 2010 is found exceeded with the desirable limit of 500 mgl-1 as prescribed by WHO and BIS. Most of the points in Kumaon rivers are showing higher desirable limit and even found exceeding with the permissible of 1000 mgl-1 of WHO at river Kosi, river Dhela and river Bhela.

High relief, tectonic disturbance and large scale human interventions may be responsible for higher sediment load in Indian rivers and thus result in high TDS and TSS (Chakrapani, 2005). TDS is found much higher in Kosi river compared to that of the study carried out during 2001-02 (Sati et al. 2008). It was observed that average value of 121.33 mgl-1 for TDS, and average value of 236.5 mgl-1 for TSS persists in river bodies of Uttarakhand (Semwal and Akolkar, 2006).

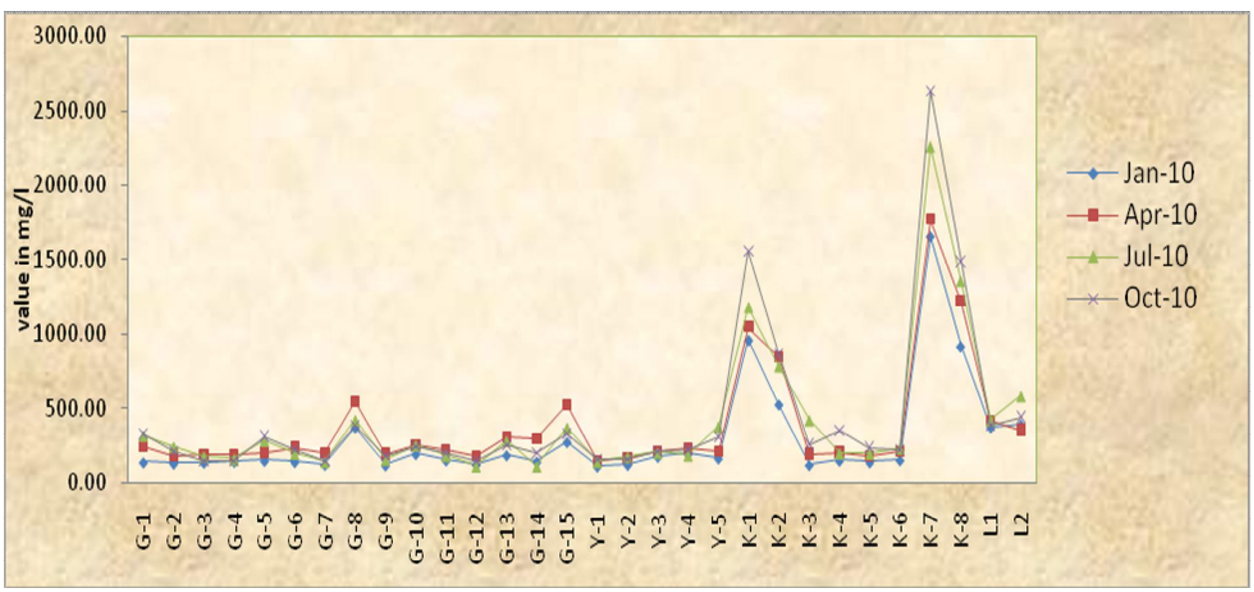
Table 4.1.11 Value of Total Dissolved Solids in mg l^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	140.00	252.00	320.00	324.00
	G-2	132.00	188.00	244.00	212.00
	G-3	138.00	194.00	180.00	148.00
	G-4	144.00	190.00	162.00	148.00
	G-5	150.00	210.00	286.00	312.00
	G-6	142.00	242.00	198.00	220.00
	G-7	124.00	204.00	142.00	148.00
	G-8	374.00	548.00	424.00	386.00
	G-9	120.00	198.00	158.00	174.00
	G-10	196.00	260.00	256.00	242.00
	G-11	154.00	222.00	184.00	198.00
	G-12	126.00	182.00	112.00	146.00
	G-13	188.00	312.00	284.00	252.00
	G-14	144.00	298.00	112.00	200.00
	G-15	276.00	524.00	372.00	326.00
River Yamuna	Y-1	112.00	152.00	142.00	158.00
	Y-2	124.00	169.00	176.00	158.00
	Y-3	178.00	216.00	204.00	212.00
	Y-4	196.00	238.00	186.00	224.00
	Y-5	167.00	212.00	380.00	308.00
Kumaon Rivers	K-1	958.00	1050.00	1180.00	1560.00
	K-2	526.00	848.00	784.00	864.00
	K-3	122.00	198.00	422.00	258.00
	K-4	152.00	210.00	202.00	348.00
	K-5	140.00	180.00	198.00	236.00
	K-6	155.00	214.00	234.00	222.00
	K-7	1650.00	1766.00	2254.00	2634.00
	K-8	915.00	1218.00	1354.00	1488.00
Lake Naini	L1	375.00	417.00	422.00	386.00
	L2	392.00	359.00	582.00	440.00

Table 4.1.12 Mean and Standard Deviation of Total Dissolved Solids

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	169.87	268.27	228.93	229.07	224.03
S.D.	68.95	115.76	94.05	76.74	95.18
River Yamuna (n=5x4)					
Mean	155.40	197.40	217.60	212.00	195.60
S.D.	35.93	35.62	93.55	61.63	61.68
Kumaon Rivers (n=8x4)					
Mean	577.25	710.50	828.50	951.25	766.88
S.D.	556.78	603.19	731.19	877.16	682.99
Lake Naini (n=2x4)					
Mean	383.50	388.00	502.00	413.00	421.63
S.D.	12.02	41.01	113.14	38.18	70.02

Fig 4.1.6 Spatial and Temporal Variations of Total Dissolved Solids in Different Water Bodies



4.1.7 Electrical Conductivity (EC): Data of electrical conductivity of all water bodies is presented in table 4.1.13 with mean and standard deviation in different river systems in table-4.1.14. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.7.

Values of EC are found varied from 122 micromho cm^{-1} to 454 micromho cm^{-1} in river Ganga System. Higher values are observed at downstream site of Utterkashi and Haridwar especially during April-2010. It varied from 150 micromho cm^{-1} to 320 micromho cm^{-1} in river Yamuna system with higher values during July-2010 at river Tons downstream of Dehradun. Higher values of EC are found in Kumaon rivers which varied from quite low concentration at few points to 1254 micromho cm^{-1}. River Kosi, Dhela, Bhela are showing higher values of EC. However, lake Naini shows linear trend of EC vary from 500 micromho cm^{-1} to 580 micromho cm^{-1}.

Average mean values of EC in river Ganga is found 221 micromho cm^{-1}, 264.93 micromho cm^{-1}, 238.53 micromho cm^{-1}, 241.60 micromho cm^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of EC is found 210.00 micromho cm^{-1}, 243.60 micromho cm^{-1}, 224.40 micromho cm^{-1} and 232.80 micromho cm^{-1} during different seasons of year 2010. Overall higher mean values are observed in Kumaon Rivers which are 401.00 micromho cm^{-1}, 509.63 micromho cm^{-1}, 486.75 micromho cm^{-1} and 475.50 micromho cm^{-1} in different seasons respectively. Mean values of EC in lake Naini are found 500.00 micromho cm^{-1} to 565.00 micromho cm^{-1} .

During 1998-1999 EC was observed to be 276.7 μscm^{-1} in Naini lake (Chakrapani, 2002). In a study carried out on river Yamuna in Uttarakhand (Singh et al. 2008), Electrical Conductivity and concentration of Total Solids were reported higher in Pre-monsoon season and lower in winter season as observed in the present. Higher concentration of TDS and TSS along with EC may be result of rock-bed interaction with flowing water (Yadav and Chakrapani, 2006).

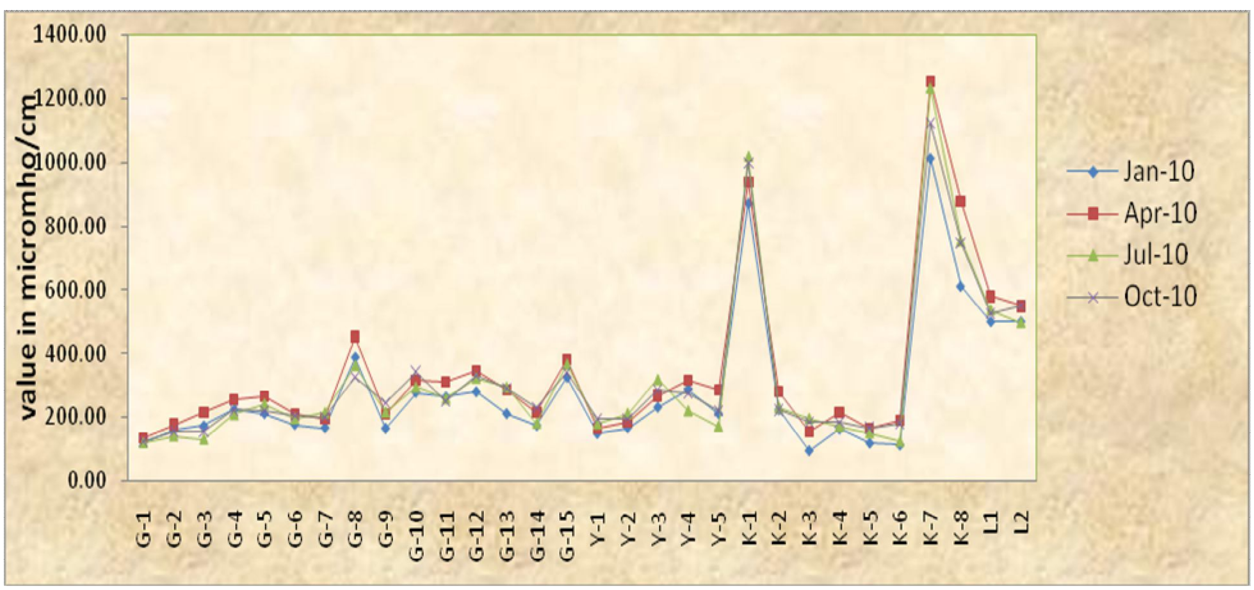
Table 4.1.13 Value of Electrical Conductivity in micromho cm^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	122.00	136.00	122.00	124.00
	G-2	160.00	178.00	144.00	156.00
	G-3	174.00	214.00	134.00	154.00
	G-4	224.00	256.00	210.00	222.00
	G-5	212.00	264.00	244.00	218.00
	G-6	178.00	210.00	198.00	204.00
	G-7	168.00	194.00	216.00	198.00
	G-8	388.00	454.00	364.00	326.00
	G-9	166.00	210.00	218.00	244.00
	G-10	278.00	316.00	296.00	342.00
	G-11	264.00	312.00	260.00	248.00
	G-12	280.00	348.00	324.00	330.00
	G-13	212.00	286.00	296.00	288.00
	G-14	175.00	214.00	184.00	230.00
	G-15	325.00	382.00	368.00	340.00
River Yamuna	Y-1	150.00	164.00	182.00	194.00
	Y-2	168.00	184.00	214.00	194.00
	Y-3	232.00	268.00	320.00	284.00
	Y-4	288.00	316.00	222.00	274.00
	Y-5	212.00	286.00	174.00	218.00
Kumaon Rivers	K-1	870.00	940.00	1020.00	998.00
	K-2	224.00	282.00	232.00	222.00
	K-3	96.00	154.00	198.00	184.00
	K-4	164.00	214.00	174.00	184.00
	K-5	120.00	164.00	154.00	166.00
	K-6	114.00	189.00	126.00	178.00
	K-7	1010.00	1254.00	1234.00	1124.00
	K-8	610.00	880.00	756.00	748.00
Lake Naini	L1	500.00	580.00	540.00	524.00
	L2	500.00	550.00	500.00	550.00

Table 4.1.14 Mean and Standard Deviation of Electrical Conductivity

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	221.73	264.93	238.53	241.60	241.70
S.D.	72.20	85.41	78.70	70.77	76.60
River Yamuna (n=5x4)					
Mean	210.00	243.60	222.40	232.80	227.20
S.D.	54.63	66.19	58.25	43.44	53.15
Kumaon Rivers (n=8x4)					
Mean	401.00	509.63	486.75	475.50	468.22
S.D.	373.47	441.50	447.56	411.67	400.90
Lake Naini (n=2x4)					
Mean	500.00	565.00	520.00	537.00	530.50
S.D.	0.00	21.21	28.28	18.38	29.60

Fig 4.1.7 Spatial and Temporal Variations of Electrical Conductivity in Different Water Bodies



4.1.8 Total Alkalinity: Total Alkalinity in all water bodies is presented in table 4.1.15 with mean and standard deviation in different river systems in table-4.1.16. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.8.

Concentration of Total Alkalinity is found varied from 46.00 mgl^{-1} to 144.00 mgl-1 in river Ganga System. Higher values are observed at downstream site of Utterkashi and Haridwar especially during January 2010 and April-2010. It varied from 72.00 mgl-1 to 168.00 mgl^{-1} in river Yamuna system with higher values during April-2010 in river Tons at downstream of Dehradun. Higher values of Total Alkalinity are found in Kumaon rivers which varied from 74.00 mgl-1 to 366.00 mgl^{-1}. River Kosi, Dhela, Bhela are showing higher values of Total Alkalinity. Industrial effluent is the main reason for higher TA. However, lake Naini shows Tallital (L-2) as compared to higher values at Mallital (L-1).

Average mean values of Total Alkalinity in river Ganga is found 97.00 mgl^{-1}, 102.13 mgl^{-1}, 95.33 mgl^{-1}, 94.00 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of TA is found 110.80 mgl^{-1}, 125.20 mgl^{-1}, 108.00 mgl^{-1} and 116.00 mgl^{-1} during different seasons of year 2010. Overall higher mean values are observed in Kumaon rivers which are 182.75 mgl^{-1}, 191.50 mgl^{-1}, 182.50 mgl^{-1} and 178.50 mgl^{-1} in different seasons respectively. Higher mean values of Total Alkalinity in lake Naini are observed during July 2010 with lower mean values in January 2010.

None of the sample during the entire study period is found exceeded with the permissible limit of total alkalinity of 600 mgl^{-1} as prescribed by BIS. All samples of river Ganga System, river Yamuna System and Lake Naini at Tallital (L-2) are also found below the desirable limit of 200 mgl^{-1}. Kumaon rivers especially river Dehla and Bhela are found exceeding with the desirable limit of 200 mgl^{-1} w.r.t. total alkalinity.

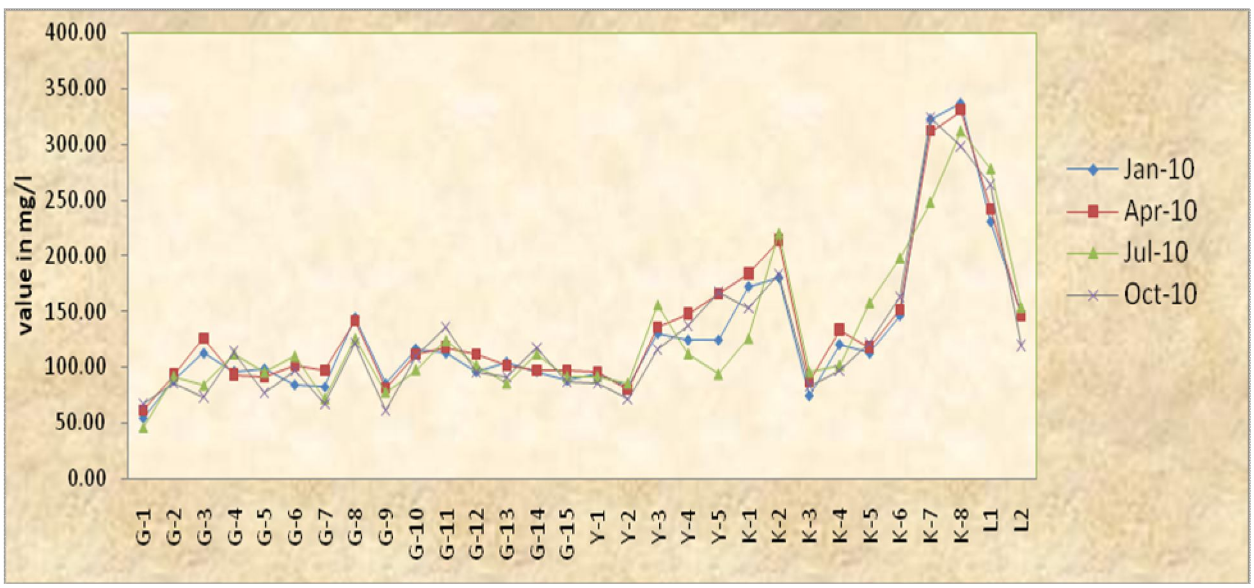
Table 4.1.15 Value of Total Alkalinity in mg l^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	54.00	62.00	46.00	68.00
	G-2	88.00	94.00	92.00	86.00
	G-3	112.00	126.00	84.00	74.00
	G-4	96.00	94.00	112.00	114.00
	G-5	98.00	92.00	96.00	78.00
	G-6	84.00	102.00	110.00	98.00
	G-7	82.00	98.00	72.00	68.00
	G-8	144.00	142.00	126.00	122.00
	G-9	85.00	82.00	78.00	62.00
	G-10	116.00	112.00	98.00	110.00
	G-11	112.00	118.00	124.00	136.00
	G-12	96.00	112.00	102.00	96.00
	G-13	104.00	102.00	86.00	92.00
	G-14	96.00	98.00	112.00	118.00
	G-15	88.00	98.00	92.00	88.00
River Yamuna	Y-1	94.00	96.00	92.00	86.00
	Y-2	82.00	80.00	86.00	72.00
	Y-3	130.00	136.00	156.00	116.00
	Y-4	124.00	148.00	112.00	138.00
	Y-5	124.00	166.00	94.00	168.00
Kumaon Rivers	K-1	172.00	184.00	126.00	154.00
	K-2	180.00	214.00	220.00	184.00
	K-3	74.00	88.00	96.00	84.00
	K-4	120.00	134.00	102.00	98.00
	K-5	112.00	118.00	158.00	122.00
	K-6	146.00	152.00	198.00	164.00
	K-7	322.00	312.00	248.00	324.00
	K-8	336.00	330.00	312.00	298.00
Lake Naini	L1	230.00	242.00	278.00	264.00
	L2	148.00	146.00	154.00	120.00

Table 4.1.16 Mean and Standard Deviation of Total Alkalinity

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	97.00	102.13	95.33	94.00	97.12
S.D.	20.04	18.72	20.88	22.26	20.23
River Yamuna (n=5x4)					
Mean	110.80	125.20	108.00	116.00	115.00
S.D.	21.38	36.04	28.53	38.81	30.06
Kumaon Rivers (n=8x4)					
Mean	182.75	191.50	182.50	178.50	183.81
S.D.	96.45	88.84	76.03	88.56	83.56
Lake Naini (n=2x4)					
Mean	189.00	194.00	216.00	192.00	197.75
S.D.	57.98	67.88	87.68	101.82	62.04

Fig 4.1.8 Spatial and Temporal Variations of Total Alkalinity in Different Water Bodies



4.1.9 Total Hardness: Total Hardness in all water bodies is presented in table 4.1.17 with mean and standard deviation in different river systems in table-4.1.18. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.9.

Concentration of Total Hardness is found varied from 160 mgl^{-1} to 286 mgl-1 in river Ganga System. Higher values are observed at downstream site of Utterkashi, Devprayag and Haridwar especially during July 2010 and October 2010. It varied from 136 mgl^{-1} to 282 mgl^{-1} in river Yamuna system with higher values during April-2010 in river Tons at downstream of Dehradun and down stream of Vikas Nagar in river Yamuna. Higher values of Total Hardness are found in Kumaon rivers which varied from 114 mgl^{-1} to 412 mgl^{-1}. River Kosi, Dhela, Bhela are showing higher values of TH. Industrial effluent is the main reason for higher Total Hardness. In lake Naini Total Hardness is found to be varied from 112 mgl^{-1} to 294 mgl^{-1}.

Average mean values of Total Hardness in river Ganga is found 185.87 mgl^{-1}, 201.33 mgl^{-1}, 177.73 mgl^{-1}, 197.00 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of Total Hardness is found 176.00 mgl^{-1}, 187.60 mgl^{-1}, 219.20 mgl^{-1} and 255.20 mgl^{-1} during different seasons of year 2010. Kumaon Rivers are found 218.75 mgl^{-1}, 228.75 mgl^{-1}, 177.88 mgl^{-1} and 245.50 mgl^{-1} in different seasons respectively. Higher mean value of Total Hardness 341 mgl^{-1} in lake Naini is observed during April 2010 with lower mean value 180.00 mgl^{-1} in October 2010.

As prescribed under "Indian Standards" desirable limit of total hardness is 300 mgl^{-1}. River Dhela and Bhela are showing higher values of Total Hardness as compared with the Indian Standards. However, these values are quite low when compared with the permissible limit of 600 mgl^{-1} of Indian Standards.

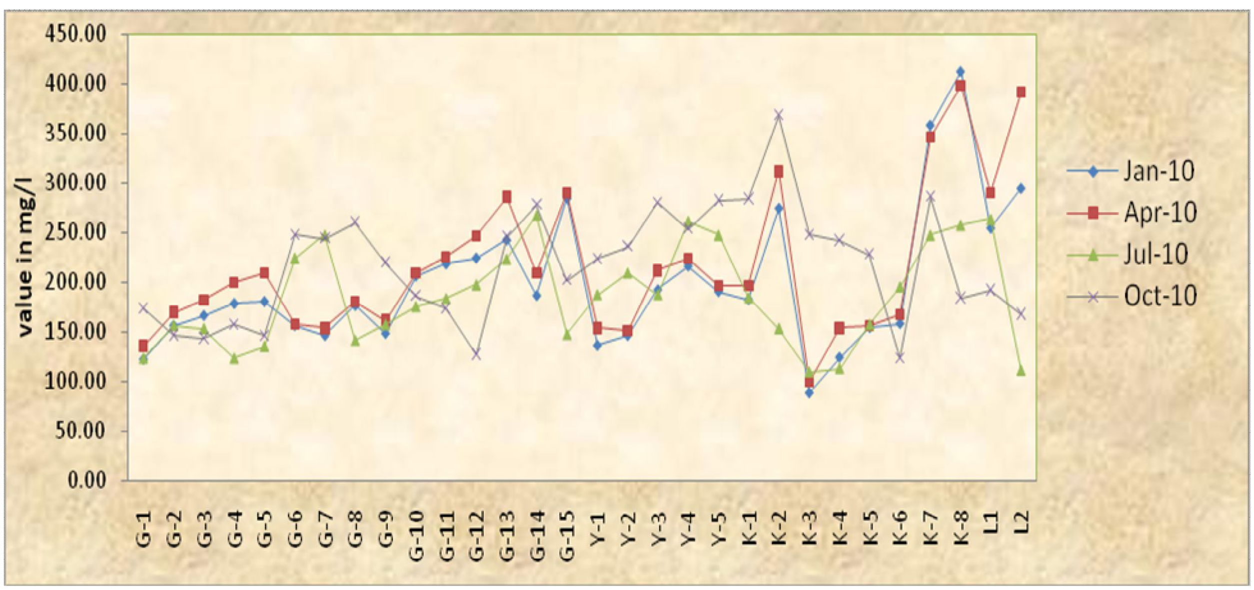
Table 4.1.17 Value of Total Hardness in mg l^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	122.00	136.00	124.00	174.00
	G-2	156.00	170.00	157.00	147.00
	G-3	166.00	182.00	154.00	144.00
	G-4	178.00	200.00	124.00	158.00
	G-5	180.00	210.00	136.00	146.00
	G-6	156.00	158.00	225.00	248.00
	G-7	146.00	154.00	248.00	244.00
	G-8	176.00	180.00	142.00	260.00
	G-9	148.00	162.00	158.00	220.00
	G-10	206.00	210.00	176.00	186.00
	G-11	218.00	226.00	184.00	174.00
	G-12	224.00	246.00	198.00	128.00
	G-13	242.00	286.00	224.00	246.00
	G-14	186.00	210.00	268.00	278.00
	G-15	284.00	290.00	148.00	202.00
River Yamuna	Y-1	136.00	154.00	188.00	224.00
	Y-2	146.00	152.00	210.00	236.00
	Y-3	192.00	212.00	188.00	280.00
	Y-4	216.00	224.00	262.00	254.00
	Y-5	190.00	196.00	248.00	282.00
Kumaon Rivers	K-1	182.00	196.00	185.00	284.00
	K-2	274.00	312.00	154.00	368.00
	K-3	88.00	100.00	110.00	248.00
	K-4	124.00	154.00	114.00	242.00
	K-5	154.00	156.00	158.00	228.00
	K-6	158.00	168.00	196.00	124.00
	K-7	358.00	346.00	248.00	286.00
	K-8	412.00	398.00	258.00	184.00
Lake Naini	L1	254.00	290.00	264.00	192.00
	L2	294.00	392.00	112.00	168.00

Table 4.1.18 Mean and Standard Deviation of Total Hardness

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	185.87	201.33	177.73	197.00	190.48
S.D.	42.38	45.99	45.49	49.04	45.58
River Yamuna (n=5x4)					
Mean	176.00	187.60	219.20	255.20	209.50
S.D.	33.73	33.12	34.25	25.87	43.06
Kumaon Rivers (n=8x4)					
Mean	218.75	228.75	177.88	245.50	217.72
S.D.	116.56	107.93	55.25	72.70	90.67
Lake Naini (n=2x4)					
Mean	274.00	341.00	188.00	180.00	245.75
S.D.	28.28	72.12	107.48	16.97	86.93

Fig 4.1.9 Spatial and Temporal Variations of Total Hardness in Different Water Bodies



Total Hardness and Total Alkalinity in river Kosi was observed from 188 mgl^{-1} to 227 mgl^{-1} and 91 mgl-1 to 200 mgl^{-1} respectively (Kumar and Bahadur, 2009). However present study had a relatively lower concentration of Total Hardness and Total Alkalinity which were 154 mgl^{-1} and 134 mgl^{-1} respectively in river Kosi which is in contradiction to the study of river Kosi (Sati et al. 2008). River Yamuna also showed higher concentration of total hardness as compared to previous study (Singh et al. 2008). During year 2004-05 average hardness in rivers of Uttarakhand was found 61 mgl-1 to 96 mgl^{-1} and average alkalinity was found 37 mg^{-1} to 96 mgl^{-1} (Semwal and Akolkar, 2006) which is quite lower than the observed value in present study. This is clear indication of increased pollution in the rivers over the years due to industrialization and infrastructure development in the state.

4.1.10 Sodium (Na): Concentration of Na in all water bodies is presented in table 4.1.19 with mean and standard deviation in different river systems in table-4.1.20. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.10.

Concentration of Na is found varied from 3.24 mgl^{-1} to 15.01 mgl-1 in river Ganga System. Higher values are observed at downstream site of Utterkashi, Devprayag, upstream and downstream of Haridwar. It varies from 1.35 mgl^{-1} to 12.32 mgl^{-1} in river Yamuna system with higher values during January-2010 in river Tons at downstream of Dehradun and downstream of Vikas Nagar in river Yamuna. Higher values of Na are found in Kumaon rivers which varied from 6.54 mgl^{-1} to 24.80 mgl^{-1}. River Gola, Dhela, Bhela are showing higher values of Na. In lake Naini Na is found to be varied from 2.42 mgl^{-1} to 3.30 mgl^{-1}.

Average mean values of Na in river Ganga is found 11.15 mgl^{-1}, 11.99 mgl^{-1}, 9.81 mgl^{-1}, 10.56 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of Na is found 8.69 mgl^{-1}, 8.65 mgl^{-1}, 7.46 mgl^{-1} and 8.21 mgl^{-1} during different seasons of year 2010. Mean values of Na in Kumaon rivers are found 10.53 mgl^{-1}, 10.68 mgl^{-1}, 9.36 mgl^{-1} and 9.47 mgl^{-1} in different seasons respectively. Overall low mean value of are observed in Naini lake. Mean values of which are found 2.66 mgl^{-1} to 3.25 mgl^{-1}.

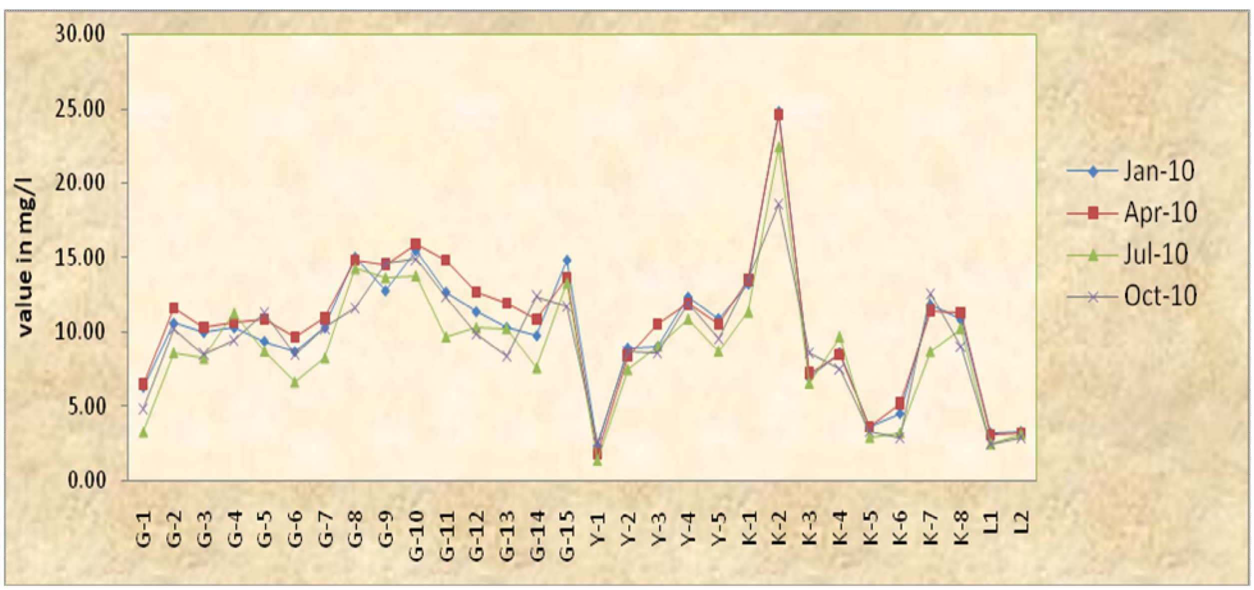
Table 4.1.19 Value of Sodium in mg l^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	6.24	6.50	3.24	4.80
	G-2	10.56	11.62	8.56	10.20
	G-3	9.94	10.32	8.20	8.50
	G-4	10.25	10.68	11.20	9.40
	G-5	9.36	10.88	8.68	11.24
	G-6	8.66	9.64	6.60	8.50
	G-7	10.25	10.92	8.22	10.24
	G-8	15.01	14.85	14.21	11.57
	G-9	12.74	14.56	13.60	14.58
	G-10	15.43	15.89	13.74	14.88
	G-11	12.65	14.84	9.64	12.30
	G-12	11.32	12.68	10.24	9.84
	G-13	10.28	11.92	10.20	8.36
	G-14	9.73	10.89	7.56	12.38
	G-15	14.81	13.64	13.24	11.67
River Yamuna	Y-1	2.33	1.85	1.35	2.50
	Y-2	8.91	8.44	7.44	8.62
	Y-3	9.01	10.52	9.02	8.55
	Y-4	12.32	11.89	10.82	11.86
	Y-5	10.87	10.54	8.68	9.54
Kumaon Rivers	K-1	13.20	13.50	11.29	13.47
	K-2	24.80	24.60	22.41	18.58
	K-3	6.90	7.25	6.54	8.59
	K-4	8.60	8.47	9.65	7.44
	K-5	3.60	3.66	2.89	3.30
	K-6	4.50	5.21	3.21	2.84
	K-7	11.80	11.45	8.66	12.57
	K-8	10.80	11.29	10.20	8.96
Lake Naini	L1	3.20	3.10	2.47	2.42
	L2	3.30	3.25	3.12	2.89

Table 4.1.20 Mean and Standard Deviation of Sodium

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	11.15	11.99	9.81	10.56	10.88
S.D.	2.55	2.47	3.04	2.57	2.72
River Yamuna (n=5x4)					
Mean	8.69	8.65	7.46	8.21	8.25
S.D.	3.83	4.00	3.62	3.46	3.46
Kumaon Rivers (n=8x4)					
Mean	10.53	10.68	9.36	9.47	10.01
S.D.	6.69	6.53	6.13	5.29	5.91
Lake Naini (n=2x4)					
Mean	3.25	3.18	2.80	2.66	2.97
S.D.	0.07	0.11	0.46	0.33	0.35

Fig 4.1.10 Spatial and Temporal Variations of Sodium in Different Water Bodies



4.1.11 Potassium (K): Concentration of Potassium in all water bodies is presented in table 4.1.21 with mean and standard deviation in different river systems in table-4.1.22. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.11.

Concentration of Potassium is found varied from 12.66 mgl^{-1} to 152.54 mgl^{-1} in river Ganga System. Higher values are observed at downstream site of Utterkashi, Devprayag, upstream and downstream of Haridwar. It varies from 11.84 mgl^{-1} to 82.57 mgl^{-1} in river Yamuna system with higher values in river Tons at downstream of Dehradun and downstream of Vikas Nagar in river Yamuna. In Kumaon rivers concentration of Potassium is found from 11.26 mgl^{-1} to 36.33 mgl^{-1}. River Gola, Dhela, Bhela are showing higher values of Potassium. In lake Naini Potassium is found to be vary from 10.27 mgl^{-1} to 14.57 mgl^{-1}.

Average mean values of Na in river Ganga is found 54.64 mgl^{-1}, 60.96 mgl^{-1}, 49.19 mgl^{-1}, 53.57 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of Potassium is found 41.21 mgl^{-1}, 42.12 mgl^{-1}, 39.20 mgl^{-1} and 35.51 mgl^{-1} during different seasons of year 2010. Mean values of Potassium in Kumaon rivers are found 22.24 mgl^{-1} in January 2010 & April 2010 both, and 22.67 mgl^{-1}, 23.64 mgl^{-1} in July 2010 and October 2010 respectively. Overall low mean value of are observed in Naini lake. Mean values of which are found 11.10 mgl^{-1} to 12.91 mgl^{-1}.

During 1999 higher values of sodium and lower values of potassium were observed in Himalayan Rivers (Chakrapani, 2005b) which is in contradiction to the results of present study. This is area of debate and further research to conduct more studies to verify the contradictory results. Very small concentrations of Sodium and Potassium were also reported in Himalayan Rivers during 2004-05 (Semwal and Akolkar, 2006).

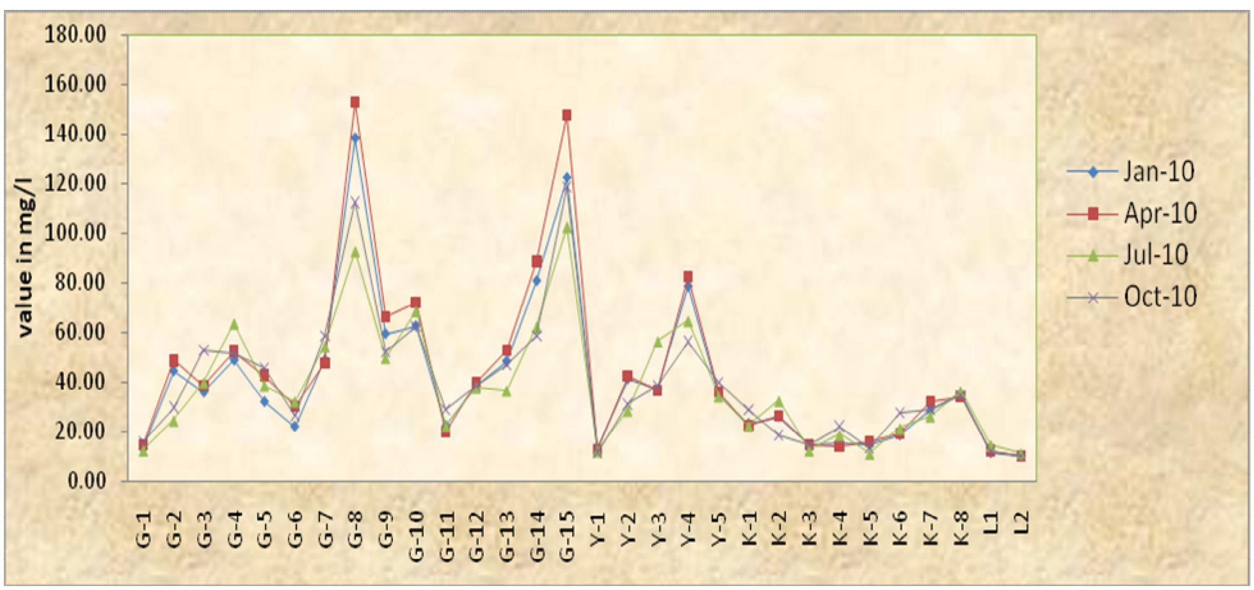
Table 4.1.21 Value of Potassium in mg l^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	13.32	14.56	12.66	15.89
	G-2	44.65	48.66	24.50	29.87
	G-3	36.15	38.64	39.88	52.62
	G-4	48.91	52.44	63.58	51.29
	G-5	32.25	42.84	38.65	45.62
	G-6	22.24	30.22	32.18	26.64
	G-7	48.91	47.68	54.31	58.43
	G-8	138.22	152.54	92.57	112.54
	G-9	59.54	66.34	49.67	52.36
	G-10	62.73	72.28	68.52	62.34
	G-11	22.54	20.12	22.39	28.96
	G-12	38.62	39.68	37.84	38.42
	G-13	48.44	52.64	36.64	46.84
	G-14	80.80	88.52	62.14	58.65
	G-15	122.27	147.28	102.36	118.54
River Yamuna	Y-1	13.60	12.80	12.36	11.84
	Y-2	41.46	42.58	28.54	31.24
	Y-3	37.21	36.54	56.27	38.31
	Y-4	78.68	82.57	64.59	56.34
	Y-5	35.09	36.10	34.25	39.84
Kumaon Rivers	K-1	23.40	22.54	22.35	28.94
	K-2	26.20	26.49	32.44	18.54
	K-3	14.80	14.87	12.57	14.66
	K-4	15.60	14.24	18.68	22.14
	K-5	14.80	15.87	11.26	13.68
	K-6	18.80	19.34	21.36	27.69
	K-7	28.90	32.25	26.33	28.94
	K-8	35.40	33.88	36.33	34.52
Lake Naini	L1	11.80	12.58	14.57	12.34
	L2	10.40	10.37	11.24	10.27

Table 4.1.22 Mean and Standard Deviation of Potassium

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	54.64	60.96	49.19	53.27	54.52
S.D.	35.28	40.77	25.24	28.64	32.46
River Yamuna (n=5x4)					
Mean	41.21	42.12	39.20	35.51	39.51
S.D.	23.56	25.32	21.18	16.12	20.19
Kumaon Rivers (n=8x4)					
Mean	22.24	22.44	22.67	23.64	22.74
S.D.	7.57	7.75	8.83	7.55	7.57
Lake Naini (n=2x4)					
Mean	11.10	11.48	12.91	11.31	11.70
S.D.	0.99	1.56	2.35	1.46	1.47

Fig 4.1.11 Spatial and Temporal Variations of Potassium in Different Water Bodies



4.1.12 Chloride (Cl): Concentration of Chloride in all water bodies is presented in table 4.1.23 with mean and standard deviation in different river systems in table-4.1.24. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.12.

Concentration of Chloriode is found ranging from Not Detectable (ND) to 21.0 mgl^{-1} in river Ganga System. Higher values are observed at downstream site of Utterkashi, Rudrapryag, Devprayag, upstream and downstream of Haridwar. It ranges from ND to 19.0 mgl^{-1} in river Yamuna system with higher values in river Tons at downstream of Dehradun and downstream of Vikas Nagar in river Yamuna. In Kumaon rivers concentration of Chloride is found ranging from ND to 27.0 mgl^{-1}. River Gola shows higher values of Chloride. In lake Naini concentration of Chloride is found to be vary from 11.00 mgl^{-1} to 19.00 mgl^{-1}.

Average mean values of Cl in river Ganga is found 11.93 mgl^{-1}, 10.53 mgl^{-1}, 8.87 mgl^{-1}, 10.33 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of Chloride is found 10.80 mgl^{-1}, 5.80 mgl^{-1}, 8.0 mgl^{-1} and 8.80 mgl^{-1} during different seasons of year 2010. Mean values of Chloride in Kumaon rivers are found 7.13 mgl^{-1} in January 2010 & April 2010 both, and 5.25 mgl^{-1}, 5.38 mgl^{-1} in July 2010 and October 2010 respectively. Overall higher mean value of are observed in Naini lake. Mean values of which are found 12.50 mgl^{-1} to 18.50 mgl^{-1}.

Average concentration of chloride was found from 8.8 mgl-1 to 20 mgl-1 in a study by Semwal and Akolkar, 2006 in Himalayan rivers and is almost near to the values observed in the present study. Chloride in river Yamuna ranged from 2.1 to 2.9 mgl-1 in a study by Singh et al., 2008. In the present study none of the water sample shows higher values of chloride when compared with the desirable limit of 250 mgl^{-1} of Indian Standards.

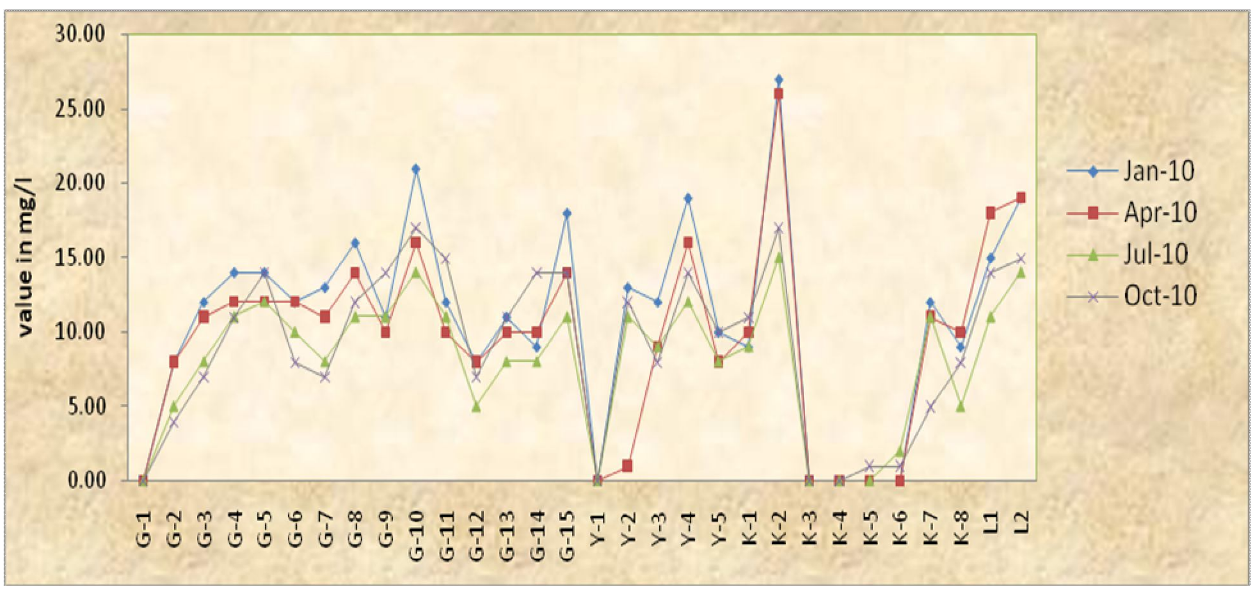
Table 4.1.23 Value of Chloride in mg l^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	0.00	0.00	0.00	0.00
	G-2	8.00	8.00	5.00	4.00
	G-3	12.00	11.00	8.00	7.00
	G-4	14.00	12.00	11.00	11.00
	G-5	14.00	12.00	12.00	14.00
	G-6	12.00	12.00	10.00	8.00
	G-7	13.00	11.00	8.00	7.00
	G-8	16.00	14.00	11.00	12.00
	G-9	11.00	10.00	11.00	14.00
	G-10	21.00	16.00	14.00	17.00
	G-11	12.00	10.00	11.00	15.00
	G-12	8.00	8.00	5.00	7.00
	G-13	11.00	10.00	8.00	11.00
	G-14	9.00	10.00	8.00	14.00
	G-15	18.00	14.00	11.00	14.00
River Yamuna	Y-1	0.00	0.00	0.00	0.00
	Y-2	13.00	1.00	11.00	12.00
	Y-3	12.00	9.00	9.00	8.00
	Y-4	19.00	16.00	12.00	14.00
	Y-5	10.00	8.00	8.00	10.00
Kumaon Rivers	K-1	9.00	10.00	9.00	11.00
	K-2	27.00	26.00	15.00	17.00
	K-3	0.00	0.00	0.00	0.00
	K-4	0.00	0.00	0.00	0.00
	K-5	0.00	0.00	0.00	1.00
	K-6	0.00	0.00	2.00	1.00
	K-7	12.00	11.00	11.00	5.00
	K-8	9.00	10.00	5.00	8.00
Lake Naini	L1	15.00	18.00	11.00	14.00
	L2	19.00	19.00	14.00	15.00

Table 4.1.24 Mean and Standard Deviation of Chloride

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	11.93	10.53	8.87	10.33	10.42
S.D.	4.85	3.64	3.50	4.70	4.25
River Yamuna (n=5x4)					
Mean	10.80	6.80	8.00	8.80	8.60
S.D.	6.91	6.53	4.74	5.40	5.67
Kumaon Rivers (n=8x4)					
Mean	7.13	7.13	5.25	5.38	6.22
S.D.	9.48	9.19	5.80	6.21	7.52
Lake Naini (n=2x4)					
Mean	17.00	18.50	12.50	14.50	15.63
S.D.	2.83	0.71	2.12	0.71	2.83

Fig 4.1.12 Spatial and Temporal Variations of Chloride in Different Water Bodies



4.1.13 Phosphate: Concentration of Phosphate in all water bodies is presented in table 4.1.25 with mean and standard deviation in different river systems in table-4.1.26. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.1.13.

Concentration of Phosphate is found ranging from Not Detectable (ND) to 657.53 μgl^{-1} in river Ganga System. Higher values are observed at downstream site of Utterkashi, Devprayag, upstream and downstream of Haridwar. It ranges from ND to 381.92 μgl^{-1} in river Yamuna system with higher values in river Tons at downstream of Dehradun and downstream of Vikas Nagar in river Yamuna. In Kumaon rivers concentration of phosphate is found ranging from ND to 646.71 μgl^{-1}. River Dhela and Bhela shows higher values of Phosphate. In lake Naini concentration of Chloride is found to be vary from 88.65 μgl^{-1} to 182.50 μgl^{-1}.

Average mean values of Phosphate in river Ganga is found 107.66 μgl^{-1}, 143.74 μgl^{-1}, 122.97 μgl^{-1}, 197.22 μgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of Chloride is found 64.53 μgl^{-1}, 124.66 μgl^{-1}, 84.23 μgl^{-1} and 104.19 μgl^{-1} during different seasons of year 2010. Mean values of Phosphate in Kumaon rivers are found 56.51 μgl^{-1}, 207.05 μgl^{-1}, 75.50 μgl^{-1}, 104.32 μgl^{-1} in January 2010, April 2010, July 2010 and October 2010 respectively. Mean value of Phosphate in Naini lake are found from 90.89 μgl^{-1} to 172.63 μgl^{-1}. Over all it is found that the concentration of Phosphate is lowest in January 2010 while higher concentration are found in April 2010. River Ganga shows relatively higher concentration as observed and compared to river Yamuna. This may be because of less human settlement and industrial growth in river Yamuna basin in Uttarakhand. Higher concentration of Phosphate results in nutrient enrichment in the water bodies and create problem of algal blooms.

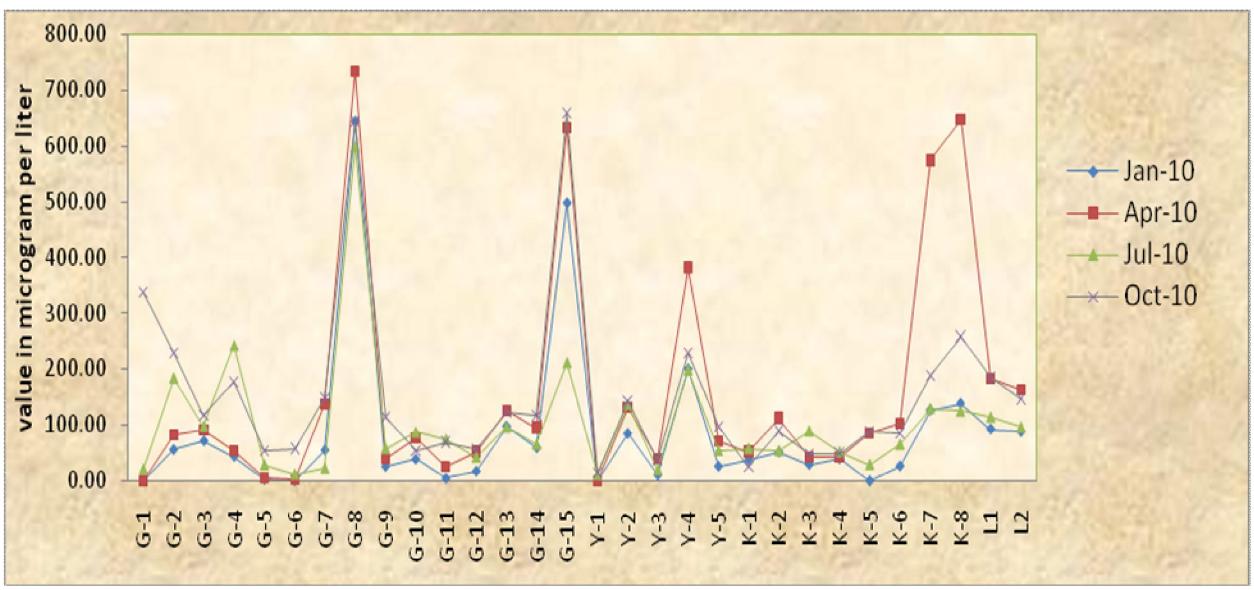
Table 4.1.25 Value of Phosphate in μgl^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	0.00	0.00	21.25	336.91
	G-2	56.13	83.44	184.25	229.37
	G-3	71.86	91.97	98.54	117.84
	G-4	44.11	53.95	242.36	177.37
	G-5	2.82	5.22	28.96	54.22
	G-6	0.00	3.47	12.54	58.24
	G-7	55.48	136.10	22.56	147.69
	G-8	642.80	732.39	598.24	642.87
	G-9	25.98	40.62	58.24	115.34
	G-10	39.09	77.76	87.36	54.21
	G-11	4.57	25.32	74.21	69.83
	G-12	17.46	52.42	42.54	56.98
	G-13	98.08	124.96	96.35	123.57
	G-14	59.85	95.24	65.58	116.35
	G-15	496.63	633.19	211.58	657.53
River Yamuna	Y-1	0.00	0.00	11.32	14.58
	Y-2	85.19	131.08	136.79	142.87
	Y-3	10.68	39.09	19.65	38.53
	Y-4	200.34	381.92	198.69	228.63
	Y-5	26.42	71.20	54.68	96.34
Kumaon Rivers	K-1	38.17	52.78	58.47	25.41
	K-2	52.30	112.56	54.21	89.65
	K-3	29.60	41.77	89.66	47.63
	K-4	39.80	42.10	52.36	49.81
	K-5	0.00	84.50	29.41	88.62
	K-6	26.80	102.22	65.69	85.27
	K-7	126.84	573.75	129.61	189.62
	K-8	138.54	646.71	124.58	258.55
Lake Naini	L1	93.12	182.50	114.22	184.68
	L2	88.65	162.76	96.58	147.33

Table 4.1.26 Mean and Standard Deviation of Phosphate

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	107.66	143.74	122.97	197.22	142.90
S.D.	191.81	223.62	149.31	199.10	190.94
River Yamuna (n=5x4)					
Mean	64.53	124.66	84.23	104.19	94.40
S.D.	82.75	151.61	80.97	85.71	98.67
Kumaon Rivers (n=8x4)					
Mean	56.51	207.05	75.50	104.32	110.84
S.D.	49.44	251.01	35.93	79.55	141.36
Lake Naini (n=2x4)					
Mean	90.89	172.63	105.40	166.01	133.73
S.D.	3.16	13.96	12.47	26.41	40.43

Fig 4.1.13 Spatial and Temporal Variations of Phosphate in Different Water Bodies



Water quality monitoring of Yamuna downstream of the Uttarakhand state has been done by Kaushik et al. (2009) and it was found that phosphate vary from 2.0 μgl^{-1} to 356.0 μgl^{-1}. Phosphate in Kosi river during 2004-05 was varying from 40.0 μgl^{-1} to 63.0 μgl^{-1} (Bhandari and Nayal, 2008) and during 2001 and 2002 it varied from 60 μgl^{-1} to 250 μgl^{-1} with higher values in pre-monsoon period (Sati and Paliwal, 2008) as observed in the present study. Phosphate concentration is found always higher in pre-monsoon season than in winter. This may be due to increase in temperature of water bodies which increase activity of bacteria presented in sewage discharging into water bodies. Decomposition of sewage results in release of Phosphate into water bodies. Sampling location G-8, G-15, Y-4, and K-8 represented higher concentration than at other stations. This may be due to sewage disposal in the river bodies. Relatively higher concentration of phosphate as compared with a study on river water quality of Uttarakhand published in 2006 (Semwal and Akolkar, 2006) showed that the concentration of phosphate in water bodies of Uttarakhand varied from 12.2 μgl^{-1} to 68.0 μgl^{-1} during 2004-05. It concludes that during four years rapid industrialization and urban development has lead to pollution in water bodies and concentration of phosphate increased manifold.

4.2 HEAVY METALS

In the present study, various water bodies were monitored for heavy metals namely Pb, Cu, Fe and Zn. Heavy metals are mainly responsible for neurological disorders and change in metabolic activities.

4.2.1 Lead (Pb): Concentration of Pb in all water bodies is presented in table 4.2.1 with mean and standard deviation in different river systems in table-4.2.2. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.2.1.

Concentration of Pb is found ranging from Not Detectable (ND) to 0.98 mgl^{-1} in river Ganga System. Higher values are observed at downstream site of

Utterkashi, Devprayag, upstream and downstream of Haridwar. It ranges from ND to 0.51 mgl^{-1} in river Yamuna system with higher values at downstream of Vikas Nagar in river Yamuna. In Kumaon rivers concentration of Pb is found ranging ND to 6.98 mgl^{-1}. River Gola, Kosi, Dhela and Bhela shows higher values of Pb. In lake Naini concentration of Pb is found to be vary from 0.21 mgl^{-1} to 0.34 mgl^{-1}.

Average mean values of Pb in river Ganga is found 0.18 mgl^{-1}, 0.32 mgl^{-1}, 0.22 mgl^{-1}, 0.26 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of Pb is found 0.07 mgl^{-1}, 0.17 mgl^{-1}, 0.15 mgl^{-1} and 0.15 mgl^{-1} during different seasons of year 2010. Mean values of Pb in Kumaon rivers are found 2.74 mgl^{-1}, 3.85 mgl^{-1}, 3.41 mgl^{-1}, 3.77 mgl^{-1} in January 2010, April 2010, July 2010 and October 2010 respectively. Mean value of Pb in Naini lake are found and vary from 0.23 mgl^{-1} to 0.31 mgl^{-1}.

As per Indian Standard Institute desirable limit of Pb is 0.01 mgl^{-1}. All observed mean values of Pb except where notdetectable were exceeding the standard limit. Very low concentration of lead in river Ganga has been observed in West Bangal (Kar et al. 2008). Higher value of Pb was found at downstream of Uttarkashi in river Bhagirathi, and upstream and downstream of Haridwar town. These two towns sustain comparatively large size of population than other towns situated along the river Ganga and its tributaries in Uttarakhand. Untreated sewage and industrial effluent may be the reason for higher values at Haridwar. However, construction activity of hydroelectric power project at Uttarkashi is the strong possible reason for increased values of Pb in river water bodies. In River Yamuna very low concentration of Pb was observed. Compared to river Ganga System, very less developmental activities and population persists along river Yamuna in the state. Higher average concentration of Pb was observed in Kumaon rivers. River bodies of Uttarakhand were found to have almost similar concentration of Pb as observed by Zaherrudin et al. (1996) in water bodies of Delhi.

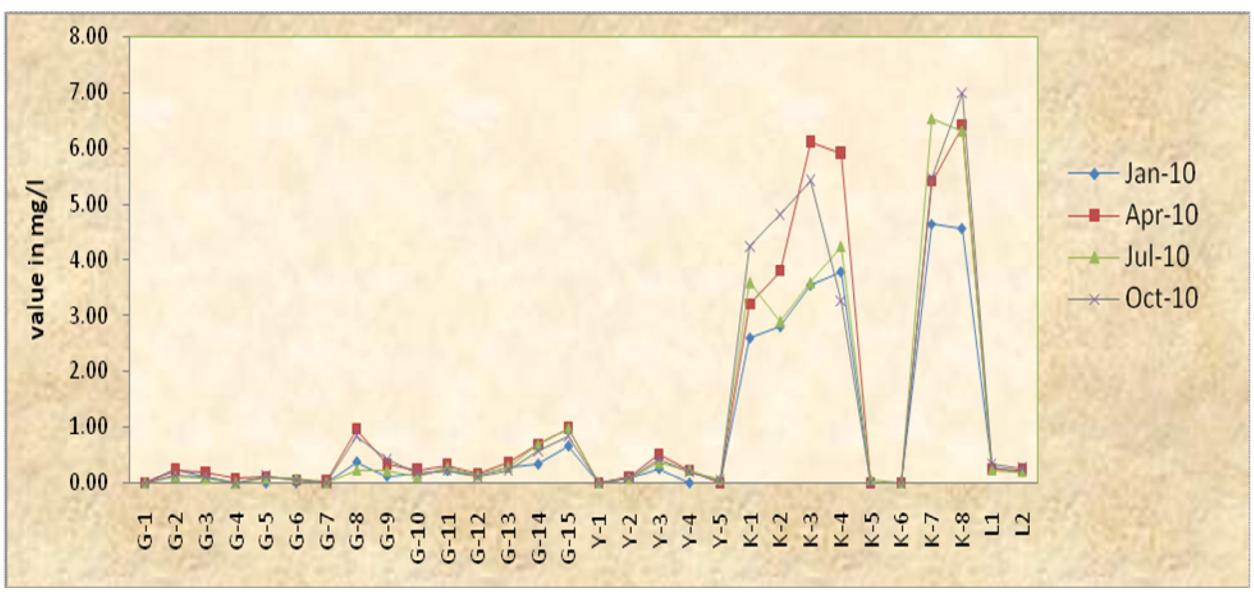
Table 4.2.1 Value of Lead (Pb) in mgl^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	0.00	0.00	0.00	0.00
	G-2	0.26	0.24	0.12	0.14
	G-3	0.11	0.19	0.08	0.11
	G-4	0.00	0.08	0.00	0.00
	G-5	0.00	0.12	0.09	0.12
	G-6	0.00	0.06	0.08	0.06
	G-7	0.00	0.04	0.00	0.00
	G-8	0.38	0.96	0.24	0.84
	G-9	0.12	0.34	0.22	0.42
	G-10	0.18	0.24	0.11	0.18
	G-11	0.22	0.33	0.28	0.24
	G-12	0.14	0.16	0.14	0.11
	G-13	0.28	0.36	0.29	0.24
	G-14	0.34	0.68	0.68	0.57
	G-15	0.66	0.98	0.98	0.84
River Yamuna	Y-1	0.00	0.00	0.00	0.00
	Y-2	0.09	0.11	0.08	0.10
	Y-3	0.26	0.51	0.36	0.42
	Y-4	0.00	0.22	0.24	0.21
	Y-5	0.00	0.00	0.06	0.04
Kumaon Rivers	K-1	2.60	3.20	3.60	4.23
	K-2	2.80	3.80	2.90	4.80
	K-3	3.54	6.10	3.60	5.42
	K-4	3.78	5.90	4.25	3.27
	K-5	0.00	0.00	0.06	0.00
	K-6	0.00	0.00	0.00	0.00
	K-7	4.63	5.40	6.54	5.47
	K-8	4.55	6.40	6.32	6.98
Lake Naini	L1	0.28	0.26	0.24	0.34
	L2	0.21	0.24	0.21	0.27

Table 4.2.2 Mean and Standard Deviation of Lead (Pb)

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	0.18	0.32	0.22	0.26	0.24
S.D.	0.19	0.31	0.27	0.28	0.27
River Yamuna (n=5x4)					
Mean	0.07	0.17	0.15	0.15	0.14
S.D.	0.11	0.21	0.15	0.17	0.16
Kumaon Rivers (n=8x4)					
Mean	2.74	3.85	3.41	3.77	3.44
S.D.	1.84	2.63	2.45	2.56	2.31
Lake Naini (n=2x4)					
Mean	0.25	0.25	0.23	0.31	0.26
S.D.	0.05	0.01	0.02	0.05	0.04

Fig 4.2.1 Spatial and Temporal Variations of Lead (Pb) in Different Water Bodies



4.2.2 Copper (Cu): Concentration of Cu in all water bodies is presented in table 4.2.3 with mean and standard deviation in different river systems in table-4.2.4. Spatial and temporal variation of temperature in different water bodies is presented in figure 3.2.2.

Concentration of Cu is found ranging from Not Detectable (ND) to 3.69 mgl^{-1} in river Ganga System. Higher values are observed at downstream site of Utterkashi, and downstream of Haridwar. It ranges from ND to 1.22 mgl^{-1} in river Yamuna system with higher values at downstream of Vikas Nagar in river Yamuna. In Kumaon rivers concentration of Cu is found 0.22 mgl^{-1} to 7.20 mgl^{-1}. River Gola, Kosi, Dhela and Bhela shows higher values of Cu. In lake Naini concentration of Cu is found to be vary from 0.14 mgl^{-1} to 0.24 mgl^{-1}.

Average mean values of Cu in river Ganga is found 0.65 mgl^{-1}, 0.99 mgl^{-1}, 1.00 mgl^{-1}, 0.83 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of Cu is found 0.39 mgl^{-1}, 0.59 mgl^{-1}, 0.36 mgl^{-1} and 0.35 mgl^{-1} during different seasons of year 2010. Mean values of Cu in Kumaon rivers are found 4.05 mgl^{-1}, 5.33 mgl^{-1}, 5.52 mgl^{-1}, 5.06 mgl^{-1} in January 2010, April 2010, July 2010 and October 2010 respectively. Mean value of Cu in Naini lake are found and vary from 0.16 mgl^{-1} to 0.23 mgl^{-1}.

As per Indian Standards desirable limit of Cu is 0.05 mgl^{-1} and maximum permissible limit is 1.5 mgl^{-1}. In river Gnaga and Yamuna, Kumaon roiver and Naini Lake all observed values of Cu are found above the desirable limit. Concentration of Cu exceeds with the permissible limit at downstream of Utterkash, Haridwar, in river Dhela, Bhela, Kosi, Gola.

It is found that water bodies of Uttarakhand have higher concentration of Cu as compared with the concentration of Cu in river Yamuna at Delhi (Zaherrudin and Shabber, 1996), and river Kaveri (Ayyadui et al. 1994).

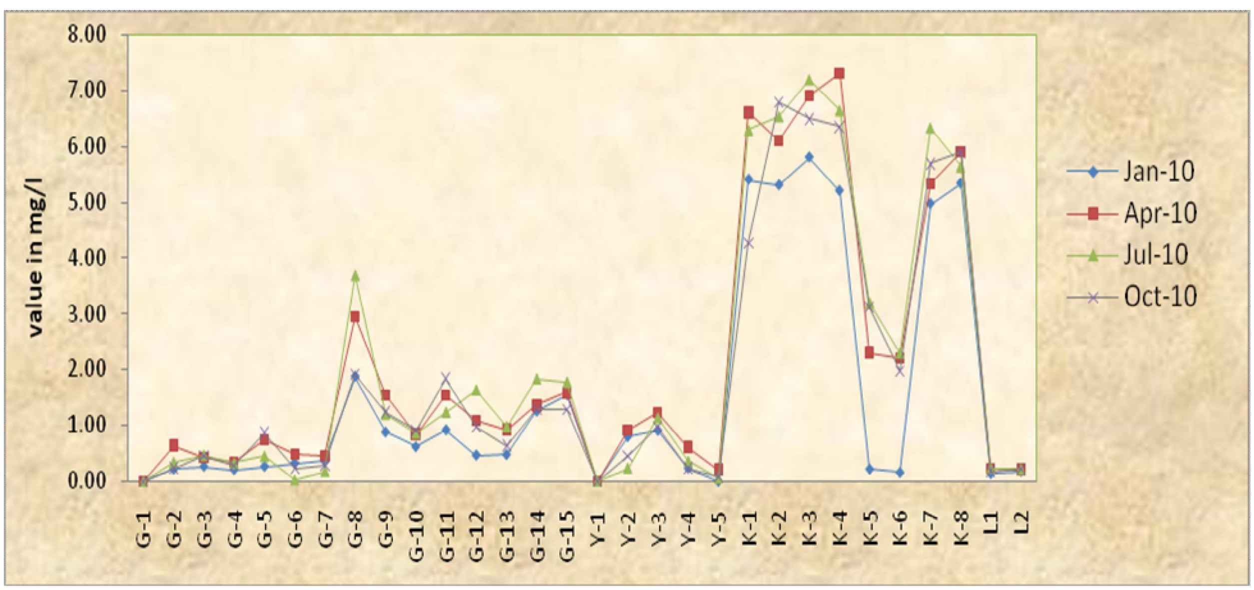
Table 4.2.3 Value of Copper (Cu) in mgl^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	0.00	0.00	0.00	0.00
	G-2	0.22	0.64	0.34	0.24
	G-3	0.27	0.42	0.47	0.45
	G-4	0.21	0.33	0.33	0.29
	G-5	0.27	0.74	0.45	0.87
	G-6	0.33	0.48	0.02	0.24
	G-7	0.36	0.45	0.18	0.29
	G-8	1.88	2.95	3.69	1.92
	G-9	0.88	1.54	1.20	1.24
	G-10	0.62	0.84	0.86	0.92
	G-11	0.92	1.54	1.24	1.84
	G-12	0.47	1.08	1.64	0.98
	G-13	0.48	0.93	0.98	0.64
	G-14	1.26	1.36	1.84	1.29
	G-15	1.55	1.59	1.78	1.29
River Yamuna	Y-1	0.00	0.00	0.00	0.00
	Y-2	0.80	0.92	0.24	0.46
	Y-3	0.91	1.22	1.14	0.97
	Y-4	0.24	0.61	0.36	0.24
	Y-5	0.00	0.21	0.06	0.09
Kumaon Rivers	K-1	5.40	6.60	6.30	4.26
	K-2	5.30	6.10	6.54	6.78
	K-3	5.80	6.90	7.20	6.48
	K-4	5.20	7.30	6.65	6.34
	K-5	0.22	2.30	3.20	3.11
	K-6	0.16	2.20	2.30	1.98
	K-7	4.97	5.32	6.34	5.68
	K-8	5.33	5.89	5.64	5.88
Lake Naini	L1	0.14	0.22	0.24	0.18
	L2	0.18	0.21	0.22	0.22

Table 4.2.4 Mean and Standard Deviation of Copper (Cu)

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	0.65	0.99	1.00	0.83	0.87
S.D.	0.55	0.73	0.97	0.60	0.72
River Yamuna (n=5x4)					
Mean	0.39	0.59	0.36	0.35	0.42
S.D.	0.44	0.50	0.46	0.39	0.42
Kumaon Rivers (n=8x4)					
Mean	4.05	5.33	5.52	5.06	4.99
S.D.	2.39	1.99	1.78	1.76	1.98
Lake Naini (n=2x4)					
Mean	0.16	0.22	0.23	0.20	0.20
S.D.	0.03	0.01	0.01	0.03	0.03

Fig 4.2.2 Spatial and Temporal Variations of Copper (Cu) in Different Water Bodies



4.2.3 Iron (Fe): Concentration of Fe in all water bodies is presented in table 4.2.5 with mean and standard deviation in different river systems in table-4.2.6. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.2.3.

Concentration of Fe is found varied from 0.11 mgl^{-1} to 0.66 mgl^{-1} in river Ganga System. Higher values are observed at downstream site of Utterkashi, and downstream of Haridwar durin July 2010. It varies from 0.11 mgl^{-1} to 0.28 mgl^{-1} in river Yamuna system. In Kumaon rivers concentration of Fe is found 0.42 mgl^{-1} to 2.24 mgl^{-1}. River Gola, Kosi, Dhela and Bhela shows higher values of Cu. In lake Naini concentration of Fe is also found higher and vary from 0.62 mgl^{-1} to 0.79 mgl^{-1}.

Average mean values of Fe in river Ganga is found 0.25 mgl^{-1}, 0.28 mgl^{-1}, 0.30 mgl^{-1}, 0.24 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of Fe is found 0.16 mgl^{-1}, 0.17 mgl^{-1}, 0.21 mgl^{-1} and 0.24 mgl^{-1} during different seasons of year 2010. Mean values of Fe in Kumaon rivers are found 0.94 mgl^{-1}, 0.99 mgl^{-1}, 1.09 mgl^{-1}, 1.03 mgl^{-1} in January 2010, April 2010, July 2010 and October 2010 respectively. Mean value of Fe in Naini lake are found and vary from 0.63 mgl^{-1} to 0.74 mgl^{-1}.

As per Indian Standards desirable limit of Fe is 0.30 mgl^{-1} and maximum permissible limit is 1.0 mgl^{-1}. As per Environment (Protection) Rules, 1986, standard limit of Fe for industrial cooling and other purpose is 0.5 mgl^{-1}. All observed values of Fe in Kumaon rivers and Naini Lake are found above the desirable limit of Indian Standards and almost except at K-6 location it is found to be exceeding by limit as prescribed under E(P) Rules, 1986. Comparatively low values of Fe are observed in river Yamuna. In river Ganga Utterkashi and Haridwar downstream site is found where Fe is exceeding with the standards desirable limits. Iron did not show many variations which clearly indicate the dominant lithological weathering as the source. Average values of Fe in river Ganga in West Bengal (Kar et al. 2008) are found almost in the same concentration observed in present study.

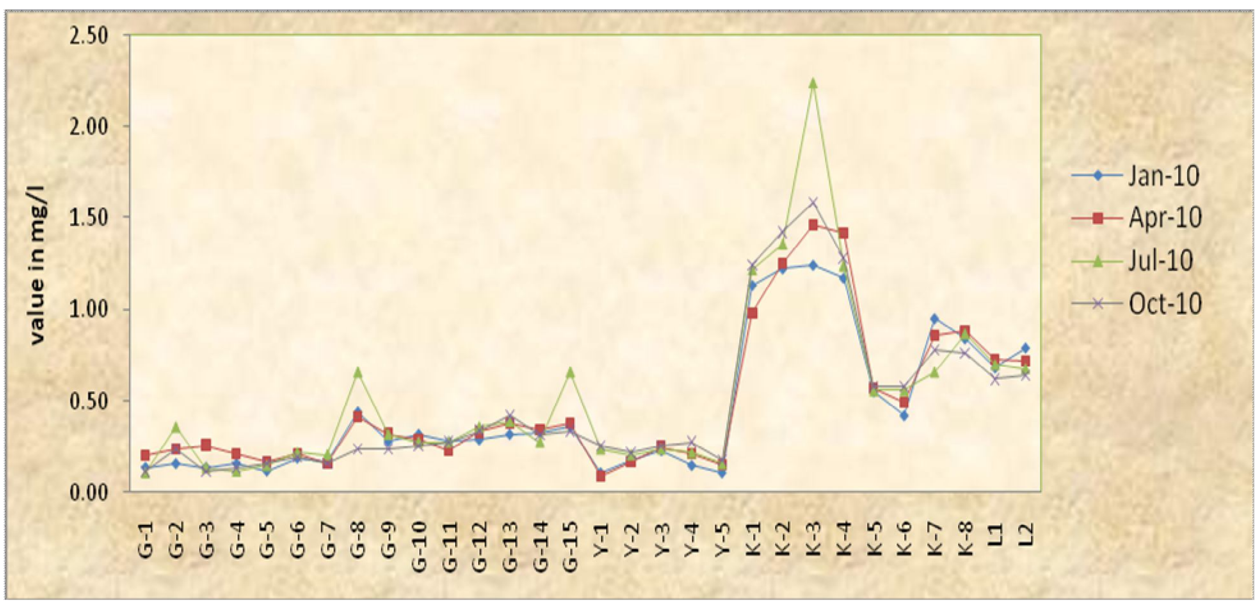
Table 4.2.5 Value of Iron (Fe) in mgl^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	0.14	0.20	0.11	0.12
	G-2	0.16	0.24	0.36	0.24
	G-3	0.14	0.26	0.14	0.12
	G-4	0.16	0.21	0.12	0.14
	G-5	0.12	0.17	0.15	0.16
	G-6	0.19	0.21	0.22	0.20
	G-7	0.17	0.16	0.21	0.16
	G-8	0.44	0.41	0.66	0.24
	G-9	0.28	0.32	0.32	0.24
	G-10	0.32	0.29	0.28	0.26
	G-11	0.28	0.23	0.28	0.28
	G-12	0.29	0.33	0.36	0.34
	G-13	0.32	0.38	0.39	0.42
	G-14	0.33	0.34	0.28	0.32
	G-15	0.36	0.38	0.66	0.34
River Yamuna	Y-1	0.11	0.09	0.24	0.26
	Y-2	0.18	0.17	0.21	0.22
	Y-3	0.23	0.25	0.24	0.26
	Y-4	0.15	0.21	0.22	0.28
	Y-5	0.11	0.15	0.16	0.18
Kumaon Rivers	K-1	1.13	0.98	1.22	1.24
	K-2	1.22	1.25	1.36	1.42
	K-3	1.24	1.46	2.24	1.58
	K-4	1.17	1.42	1.24	1.28
	K-5	0.55	0.57	0.56	0.58
	K-6	0.42	0.49	0.56	0.58
	K-7	0.95	0.86	0.66	0.78
	K-8	0.84	0.88	0.87	0.76
Lake Naini	L1	0.68	0.73	0.70	0.62
	L2	0.79	0.72	0.68	0.64

Table 4.2.6 Mean and Standard Deviation of Iron (Fe)

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	0.25	0.28	0.30	0.24	0.27
S.D.	0.10	0.08	0.17	0.09	0.12
River Yamuna (n=5x4)					
Mean	0.16	0.17	0.21	0.24	0.20
S.D.	0.05	0.06	0.03	0.04	0.06
Kumaon Rivers (n=8x4)					
Mean	0.94	0.99	1.09	1.03	1.01
S.D.	0.31	0.36	0.56	0.40	0.40
Lake Naini (n=2x4)					
Mean	0.74	0.73	0.69	0.63	0.70
S.D.	0.08	0.01	0.01	0.01	0.05

Fig 4.2.3 Spatial and Temporal Variations of Iron (Fe) in Different Water Bodies



4.2.4 Zinc (Zn): Concentration of Zn in all water bodies is presented in table 4.2.7 with mean and standard deviation in different river systems in table-4.2.8. Spatial and temporal variation of temperature in different water bodies is presented in figure 4.2.4.

Concentration of Zn is found ranging from Not Detectable (ND) to 0.64 mgl^{-1} in river Ganga System. Higher values are observed at downstream site of Utterkashi, and downstream of Haridwar during July 2010. It isalso ranging from ND to 0.16 mgl^{-1} in river Yamuna system. In Kumaon rivers concentration of Zn is found ranging from ND to 0.18 mgl^{-1}. In lake Naini concentration of Zn is also found higher and vary from 0.02 mgl^{-1} to 0.08 mgl^{-1}.

Average mean values of Zn in river Ganga is found 0.06 mgl^{-1}, 0.09 mgl^{-1}, 0.14 mgl^{-1}, 0.11 mgl^{-1} during January 2010, April 2010, July 2010 and October 2010 respectively. In river Yamuna system mean values of Zn is found 0.02 mgl^{-1}, 0.06 mgl^{-1}, 0.06 mgl^{-1} and 0.04 mgl^{-1} during different seasons of year 2010. Mean values of Zn in Kumaon rivers are found 0.05 mgl^{-1}, 0.10 mgl^{-1}, 0.08 mgl^{-1}, 0.10 mgl^{-1} in January 2010, April 2010, July 2010 and October 2010 respectively. Mean value of Fe in Naini lake are found and vary from 0.03 mgl^{-1} to 0.08 mgl^{-1}.

As per Indian Standards desirable limit of Zn is 5.0 mgl^{-1}. Zinc shows lower concentrations among all studied metals in the present study. Zn was found almost constant in all water bodies. None of the sample is exceeding with the desirable limit for Zn when compared with Indian Standards.

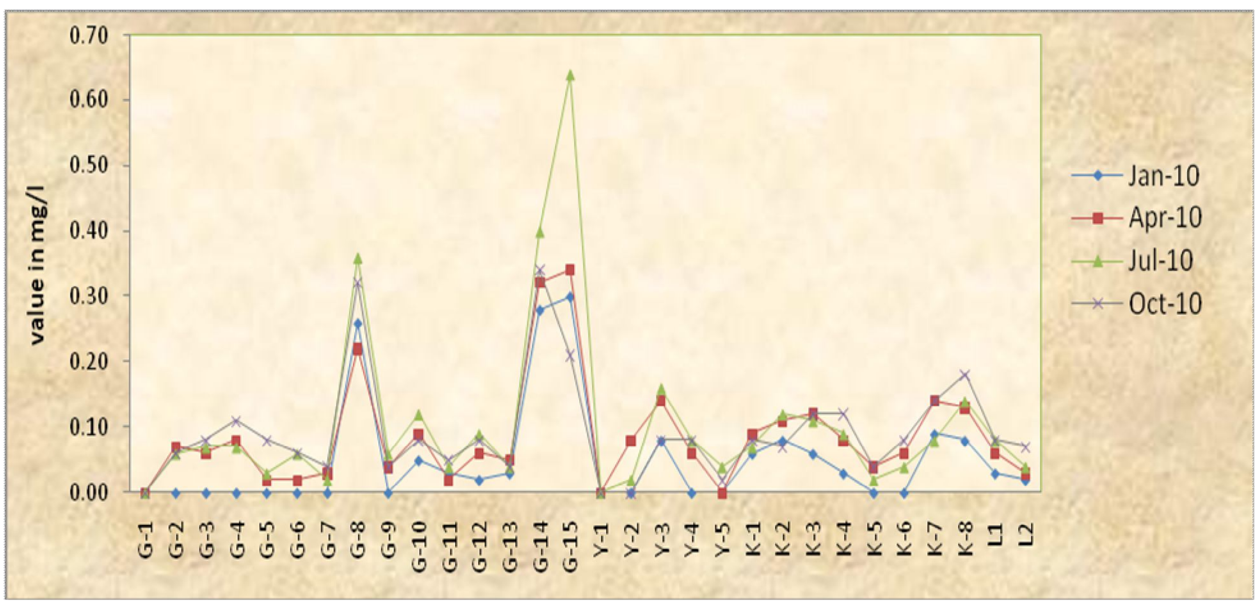
Table 4.2.7 Value of Zinc (Zn) in mgl^{-1} in Different Water Bodies during Different Seasons

Sampling Point		Jan-10	Apr-10	Jul-10	Oct-10
River Ganga System	G-1	0.00	0.00	0.00	0.00
	G-2	0.00	0.07	0.06	0.06
	G-3	0.00	0.06	0.07	0.08
	G-4	0.00	0.08	0.07	0.11
	G-5	0.00	0.02	0.03	0.08
	G-6	0.00	0.02	0.06	0.06
	G-7	0.00	0.03	0.02	0.04
	G-8	0.26	0.22	0.36	0.32
	G-9	0.00	0.04	0.06	0.04
	G-10	0.05	0.09	0.12	0.08
	G-11	0.03	0.02	0.04	0.05
	G-12	0.02	0.06	0.09	0.08
	G-13	0.03	0.05	0.04	0.04
	G-14	0.28	0.32	0.40	0.34
	G-15	0.30	0.34	0.64	0.21
River Yamuna	Y-1	0.00	0.00	0.00	0.00
	Y-2	0.00	0.08	0.02	0.00
	Y-3	0.08	0.14	0.16	0.08
	Y-4	0.00	0.06	0.08	0.08
	Y-5	0.00	0.00	0.04	0.02
Kumaon Rivers	K-1	0.06	0.09	0.07	0.08
	K-2	0.08	0.11	0.12	0.07
	K-3	0.06	0.12	0.11	0.12
	K-4	0.03	0.08	0.09	0.12
	K-5	0.00	0.04	0.02	0.04
	K-6	0.00	0.06	0.04	0.08
	K-7	0.09	0.14	0.08	0.14
	K-8	0.08	0.13	0.14	0.18
Lake Naini	L1	0.03	0.06	0.08	0.08
	L2	0.02	0.03	0.04	0.07

Table 4.2.8 Mean and Standard Deviation of Zinc (Zn)

	Jan-10	Apr-10	Jul-10	Oct-10	all Seasons
River Ganga System (n=15x4)					
Mean	0.06	0.09	0.14	0.11	0.10
S.D.	0.11	0.11	0.18	0.10	0.13
River Yamuna (n=5x4)					
Mean	0.02	0.06	0.06	0.04	0.04
S.D.	0.04	0.06	0.06	0.04	0.05
Kumaon Rivers (n=8x4)					
Mean	0.05	0.10	0.08	0.10	0.08
S.D.	0.04	0.04	0.04	0.04	0.04
Lake Naini (n=2x4)					
Mean	0.03	0.05	0.06	0.08	0.05
S.D.	0.01	0.02	0.03	0.01	0.02

Fig 4.2.4 Spatial and Temporal Variations of Zinc (Zn) in Different Water Bodies



4.3 STATISTICAL ANALYSIS

Data of water quality in different seasons is analysed statistically by using correlation study and Analysis of Variance. Level of significance has been performed spatially and temporally. Correlation of different physicochemical parameters in different seasons is given in Table 4.3.1, 4.3.2, 4.3.3 and 4.3.4 for January 2010, April 2010, July 2010 and October 2010. From the data analysis it reveals that Dissolved Oxygen has strong negative correlation with other physicochemical parameters at 0.05 level of significance except pH. It means increase or decrease in pH directly affect the concentration of Dissolved Oxygen. Biological Oxygen Demand shows a mirror image pattern of correlation as observed in case of Dissolved Oxygen. Negative correlation is also observed of pH with other physic chemical parameters except positive correlation with Potassium in all seasons, Chloride in April 2010, July 2010 and October 2010, Sodium in April 2010 and July 2010. All other parameters during all seasons almost show strong positive correlation with each other. Correlation matrix of Heavy metals is presented at table No 4.3.5 which clearly indicates positive correlation with each other in all seasons. Interrelationship of different heavy metals with some important physicochemical parameters as presented in Table 4.3.6 indicates that Pb, Cu and Fe shows negative correlation with DO and pH and positive correlation with EC and Phosphate. However, Zn shown negative correlation with DO, positive correlation with pH, EC and Phosphate.

In the present study all metals showed negative correlation with DO and pH mean more organic load in the water bodies more will be the concentration of heavy metals because organic matter provide surface for lechation of metals in acidic conditions. Metals showed positive correlation with Electrical Conductivity. Higher concentration of TDS and TSS along with EC may be result of rock-bed interaction with flowing water (Yadav and Chakrapani 2006). High relief, tectonic disturbance and large scale human interventions may be responsible for higher sediment load in Indian rivers and thus result in high TDS and TSS (Chakrapani 2005) which simultaneously could be the region for positive correlation of EC with metals in the present study. All metals showed positive correlation with each other in the present study. Lead showed strong positive correlation with Cu and Fe, where Cu and Fe itself strongly positive correlated.

Data were alanysed statistically by using ANNOVA on MS EXCEL. ANNOVA for spatial and temporal variation of Heavy metals and physicochemical parameters is presented in table 4.3.7 and 4.3.8. Calculation of Spatial Variation and Temporal Variation by using ANVOVA for a single parameter (for reference only) is presented in Appendix-I. From table 4.3.7 and 4.3.8 it was found that distribution of Fe in river Yamuna System and Zn in Kumaon rivers during the four seasons is significantly difference at 90% level of significance. However all the metals in different river systems not show and significant difference temporally even at 95% level of significance. Spatially all the metals have shown very significant difference in their distribution amongst different river systems. Temperature and Total Dissolved Solids in river Ganga System, Turbidity and Total hardness in river Yamuna System are showing significant difference temporally at 95% level of significance. Dissolved Oxygen and Phosphate in Kumaon rivers is found significantly differ at 80% level of confidence. While analyzing spatially, Phosphate and Total Hardness are not shown any significant difference. However remaining parameters have shown highly significant difference in their spatial distribution amongst different river systems.

Table 4.3.1 Correlation of Different Physicochemical Parameters in January 2010

	BOD	pH	Tem	PO4	TH	TA	TDS	TSS	Cl	Na	K	EC
DO	-0.81#	0.34#	-0.65#	-0.20#	-0.84#	-0.78#	-0.75#	-0.80#	-0.31#	-0.36#	**0.01**	-0.69#
BOD		-0.33#	0.38#	0.11*	0.79#	0.91#	0.85#	0.93#	**-0.01**	0.18#	-0.11*	0.71#
pH			-0.29#	**-0.02**	**-0.04**	-0.44#	-0.32#	-0.29#	**-0.08**	**-0.02**	0.22#	-0.26#
Tem				0.24#	0.52#	0.51#	0.45#	0.38#	0.50#	0.48#	0.09*	0.45#
PO4					0.26#	0.14#	0.17#	0.31#	0.33#	0.30#	0.82#	0.2#3
TH						0.84#	0.73#	0.85#	0.42#	0.25#	**0.04**	0.71#
TA							0.87#	0.90#	0.14#	0.11*	-0.17#	0.80#
TDS								0.84#	0.15#	0.22#	-0.09*	0.93#
TSS									0.13#	0.12#	**0.04**	0.77#
Cl										0.65#	0.40#	0.22#
Na											0.13#	0.46#
K												**-0.04**

significant at 0.01 level, * significant at 0.05 level

Table 4.3.2 Correlation of Different Physicochemical Parameters in April 2010

	BOD	pH	Tem	PO4	TH	TA	TDS	TSS	Cl	Na	K	EC
DO	-0.84#	0.40#	-0.72#	-0.41#	-0.39#	-0.61#	-0.63#	-0.49#	-0.04	-0.22#	0.12#	-0.51#
BOD		0.62#	0.53#	0.31#	0.27#	0.62#	0.57#	0.47#	-0.16#	0.05	-0.28#	0.43#
pH			-0.37#	-0.06	-0.13#	-0.49#	-0.34#	-0.25#	0.23#	0.29#	0.53#	-0.24#
Tem				0.36#	0.93#	0.53#	0.48#	0.39#	0.33#	0.34#	0.02	0.45#
PO4					0.56#	0.61#	0.66#	0.77#	0.26#	0.17#	0.53#	0.63#
TH						0.73#	0.66#	0.73#	0.59#	0.17#	-0.03	0.69#
TA							0.86#	0.86#	0.29#	0.10*	0.21#	0.84#
TDS								0.86#	0.28#	0.28#	-0.03	0.92#
TSS									0.18#	0.07	0.01	0.86#
Cl										0.56#	0.29#	0.27#
Na											0.41#	0.10*
K												-0.06

significant at 0.01 level, * significant at 0.05 level

Table 4.3.3 Correlation of Different Physicochemical Parameters in July 2010

	BOD	pH	Tem	PO4	TH	TA	TDS	TSS	Cl	Na	K	EC
DO	-0.68#	0.55#	-0.73#	-0.11*	-0.22#	-0.52#	-0.43#	-0.47#	0.01	-0.30#	-0.1*	-0.36#
BOD		-0.36#	0.64#	-0.04	0.27#	0.69#	0.84#	0.71#	-0.1*	0.16#	-0.24#	0.72#
pH			-0.37#	0.01	-0.08	-0.56#	-0.21#	-0.30#	0.17#	0.10*	0.31#	-0.13#
Tem				0.13#	0.22#	0.64#	0.54#	0.58#	0.23#	0.31#	0.15#	0.53#
PO4					-0.11*	0.04	0.08*	0.18#	0.25#	0.28#	0.56#	0.11*
TH						0.41#	0.30#	0.48#	0.09*	-0.10*	0.04	0.34#
TA							0.67#	0.75#	0.07*	-0.01	-0.24#	0.59#
TDS								0.82#	0.16#	0.14#	0.18#	0.92#
TSS									0.05	0.04	-0.03	0.74#
Cl										0.53#	0.44#	0.24#
Na											0.54#	0.05
K												-0.10*

significant at 0.01 level, * significant at 0.05 level

Table 4.3.4 Correlation of Different Physicochemical Parameters in October 2010

	BOD	pH	Tem	PO4	TH	TA	TDS	TSS	Cl	Na	K	EC
DO	-0.69#	0.55#	-0.73#	-0.11*	-0.22#	-0.53#	-0.43#	-0.47#	0.01	-0.30#	-0.10*	-0.36#
BOD		-0.36#	0.64#	-0.04	0.27#	0.69#	0.84#	0.70#	-0.10*	0.16#	-0.25#	0.72#
pH			-0.37#	0.01	-0.08*	-0.55#	-0.21#	-0.30#	0.17#	-0.10*	0.31#	-0.13#
Tem				0.13#	0.22#	0.64#	0.54#	0.58#	0.23#	0.32#	0.15#	0.53#
PO4					-0.10*	0,04	0.09*	0.18#	0.25#	0.28#	0.56#	0.10*
TH						0.41#	0.29#	0.48#	0.09*	-0.10*	0.05	0.34#
TA							0.67#	0.75#	0.07	-0.01	0.24#	0.60#
TDS								0.82#	0.16#	0.14#	-0.18#	0.92#
TSS									0.05	0.04	-0.03	0.74#
Cl										0.53#	0.44#	0.23#
Na											0.55#	0.05
K												-0.10*

significant at 0.01 level, * significant at 0.05 level

Table 4.3.5 Correlation matrix of Different Heavy Metals

	Pb Apr	**Pb Jul**	**Pb Oct**	**Cu Jan**	**Cu Apr**	**Cu Jul**	**Cu Oct**	**Fe Jan**	**Fe Apr**	**Fe Jul**	**Fe Oct**	**Zn Jan**	**Zn Apr**	**Zn Jul**	**Zn Oct**
Pb Jan	0.99	0.99	0.97	0.95	0.91	0.90	0.92	0.82	0.81	0.69	0.76	0.21	0.28	**0.07**	0.30
Pb Apr		0.96	0.97	0.96	0.93	0.91	0.93	0.83	0.84	0.76	0.78	0.22	0.29	**0.09**	0.34
Pb Jul			0.96	0.91	0.86	0.85	0.87	0.76	0.74	0.61	0.68	0.22	0.29	**0.07**	0.33
Pb Oct				0.96	0.90	0.90	0.92	0.82	0.80	0.73	0.77	0.23	0.30	**0.09**	0.32
Cu Jan					0.97	0.95	0.95	0.87	0.86	0.81	0.84	0.30	0.35	0.16	0.39
Cu Apr						0.99	0.97	0.89	0.86	0.81	0.84	0.30	0.35	0.16	0.35
Cu Jul							0.98	0.88	0.88	0.83	0.87	0.30	0.35	0.15	0.38
Cu Oct								0.89	0.88	0.81	0.86	0.21	0.28	**0.07**	0.30
Fe Jan									0.98	0.90	0.96	0.19	0.22	**0.05**	0.23
Fe Apr										0.93	0.97	0.15	0.19	**0.04**	0.22
Fe Jul											0.94	0.21	0.24	0.13	0.23
Fe Oct												**0.08**	0.14	**-0.02**	0.11
Zn Jan													0.94	0.94	0.86
Zn Apr														0.93	0.85
Zn Jul															0.78

Table 4.3.6 Interrelationships of Different Heavy Metals with some Physicochemical Parameters

	Cu	**Fe**	**Zn**	**DO**	**pH**	**EC**	**PO4**
Pb	0.90	0.77	0.19	-0.52	-0.32	0.59	0.13
Cu		0.87	0.24	-0.57	-0.33	0.45	0.11
Fe			0.16	-0.43	-0.37	0.36	0
Zn				-0.17	0.03	0.17	0.52
DO					0.36	-0.48	-0.22
pH						-0.18	-0.01
EC							0.29

Table 4.3.7 Analysis of Variance (ANNOVA) of Spatial and Temporal Variation of Heavy Metals

Temporal Variation						
Parameter	River Ganga System df = 3		River Yamuna System df = 3		Kumaon Rivers df = 3	
	F	F-critical (0.05)	F	F-critical (0.05)	F	F-critical (0.05)
Pb	0.73	2.76	0.4	3.2	0.4	2.9
Cu	0.8	2.76	0.3	3.2	0.9	2.9
Zn	0.8	2.76	0.8	3.2	**2.9**	2.9 **2.3 (0.1)**
Fe	1.0	2.76	**3.24**	3.2 **2.46 (0. 1)**	0.2	2.9
Spatial Variation						
Parameter	River Ganga System df = 59		River Yamuna System df = 19		Kumaon Rivers df = 31	
	F	F-critical (0.05)	F	F-critical (0.05)	F	F-critical (0.05)
Pb	**18.1**	1.92	**20.2**	3.14	**28.3**	2.41
Cu	**18.0**	1.92	**23.1**	3.14	**20.6**	2.41
Zn	**18.9**	1.92	**8.4**	3.14	**5.5**	2.41
Fe	**8.2**	1.92	2.2	3.14	**20.2**	2.41

Table 4.3.8 Analysis of Variance (ANNOVA) of Spatial and Temporal Variation of Physicochemical Parameters

Temporal Variation						
Parameter	River Ganga System df = 3		River Yamuna System df = 3		Kumaon Rivers df = 3	
	F	F-critical (0.05)	F	F-critical (0.05)	F	F-critical (0.05)
DO	0.67	2.76	1.75	3.2	**2.2**	2.9 1.65 (0.20)
BOD	0.87	2.76	1.1	3.2	0.88	2.9
pH	1.7	2.76	0.9	3.2	1.1	2.9
Temp.	**3.1**	2.76	0.1	3.2	**2.4**	2.9 2.3 (0.10)
PO4	0.6	2.76	0.3	3.2	**1.97**	2.9 1.65 (0.20)
Turbidity	1.06	2.76	**4.6**	3.2	0.08	2.9
Total hardness	0.8	2.76	**6.2**	3.2	0.8	2.9
Total Alkalinity	0.5	2.76	0.3	3.2	0.03	2.9
TDS	3.0	2.76	1.0	3.2	0.3	2.9
TSS	0.3	2.76	0.3	3.2	0.1	2.9
Chloride	1.3	2.76	0.4	3.2	0.1	2.9
Sodium	1.8	2.76	0.1	3.2	0.1	2.9
Potassium	0.3	2.76	0.1	3.2	0.08	2.9
Electrical Conductivity	0.8	2.76	0.3	3.2	0.1	2.9
Spatial Variation						
Parameter	River Ganga System df = 59		River Yamuna System df = 19		Kumaon Rivers df = 31	
	F	F-critical (0.05)	F	F-critical (0.05)	F	F-critical (0.05)
DO	**20.0**	1.92	**7.1**	3.14	**6.05**	2.41
BOD	**13**	1.92	**9.7**	3.14	**6.0**	2.41
pH	**9.1**	1.92	**8.7**	3.14	**2.8**	2.41
Temp.	**11.23**	1.92	**36.3**	3.14	**2.8**	2.41
PO4	**20.2**	1.92	**21.1**	3.14	**3.2**	2.41
Turbidity	**9.2**	1.92	1.9	3.14	**40.2**	2.41
Total hardness	**2.5**	1.92	1.9	3.14	**4.5**	2.41
Total Alkalinity	**11.4**	1.92	**7.8**	3.14	**59.1**	2.41
TDS	**8.2**	1.92	**4.5**	3.14	**30.2**	2.41
TSS	**41.2**	1.92	**27.4**	3.14	**110.8**	2.41
Chloride	**14.2**	1.92	**14.2**	3.14	**33.5**	2.41
Sodium	**13.3**	1.92	**98.2**	3.14	**72.2**	2.41
Potassium	**20.8**	1.92	**28.7**	3.14	**36.2**	2.41
Electrical Conductivity	**27.3**	1.92	**7.8**	3.14	**161.8**	2.41

4.4 IMPACT OF POLLUTION

From the results it is clear that river Kosi, river Dhela and river Behela are most polluted as these rivers receives maximum pollution load due to high industrial density along their cost. Majority of pollution load is derived from Pulp and paper industries which contributes both pollution and volume to rivers. However, there is not much significant impact of sewage is found. River of Garhwal regions are normally not polluted as there is not much industrial discharge. Due to higher water discharging industries Kumaon rivers are most polluted.

Data of pollution load has been complied since Jan 2006 to October 2010 (for river Dhela, Bhela, Kosi) from Uttarakhand Environment Protection and Pollution Control Board (presented in Appendix-2, which is computed for next 10 years for trend analysis by using linear regressing analysis. This was applied in river Kosi, Dhela and Bhela which are found more polluted in the present study. In river Dhela pollution load, if entering at present rate, will increase up to 8000 KG/day in 2020 while it is at present 4000-5000 Kg/day. In river Bhela, no significant change is found it will increase from 1500 to 1700 Kg/day at the end of 2020. Similarly in river Kosi pollution load will increase from 1700 to 3000 KG/day in the coming 10 years.

Predicted pollution load in river Dhela, Bhela and Kosi is presented in figure 4.4.1, 4.4.2, 4.4.3 respectively. Trend of pollution (in linear graph) for above three rivers is presented in figure 4.4.4, 4.4.5 and 4.4.6 respectively. Form the above data as also presented in table 4.4.1 it is predicted that the pollution load in river Dhela will go up to 140000Kg/day by year 2020, in river Bhela it will go up to 1700 Kg/day and in river Kosi pollution load will go up to 48000 Kg/day by the year 2020.

Fig 4.4.1 Prediction of pollution load in river Dhela

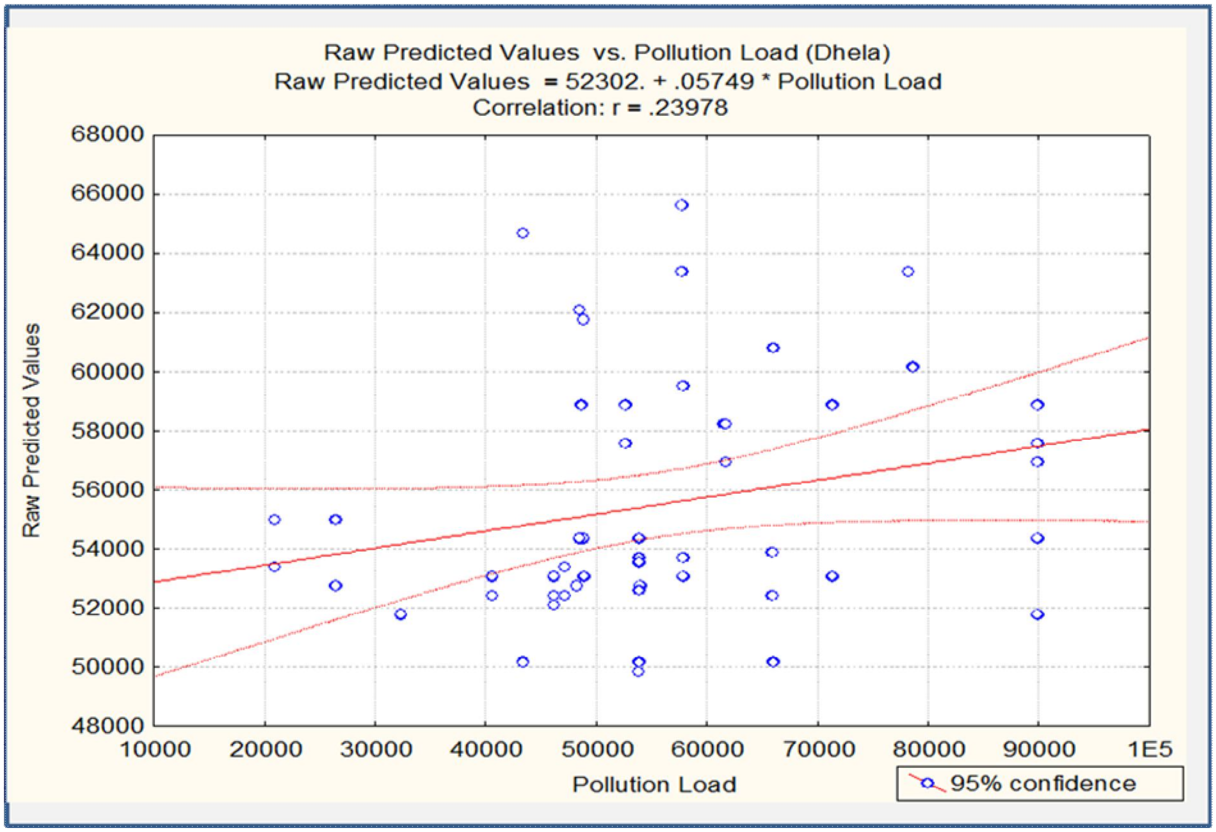


Fig 4.4.2 Prediction of pollution load in river Bhela

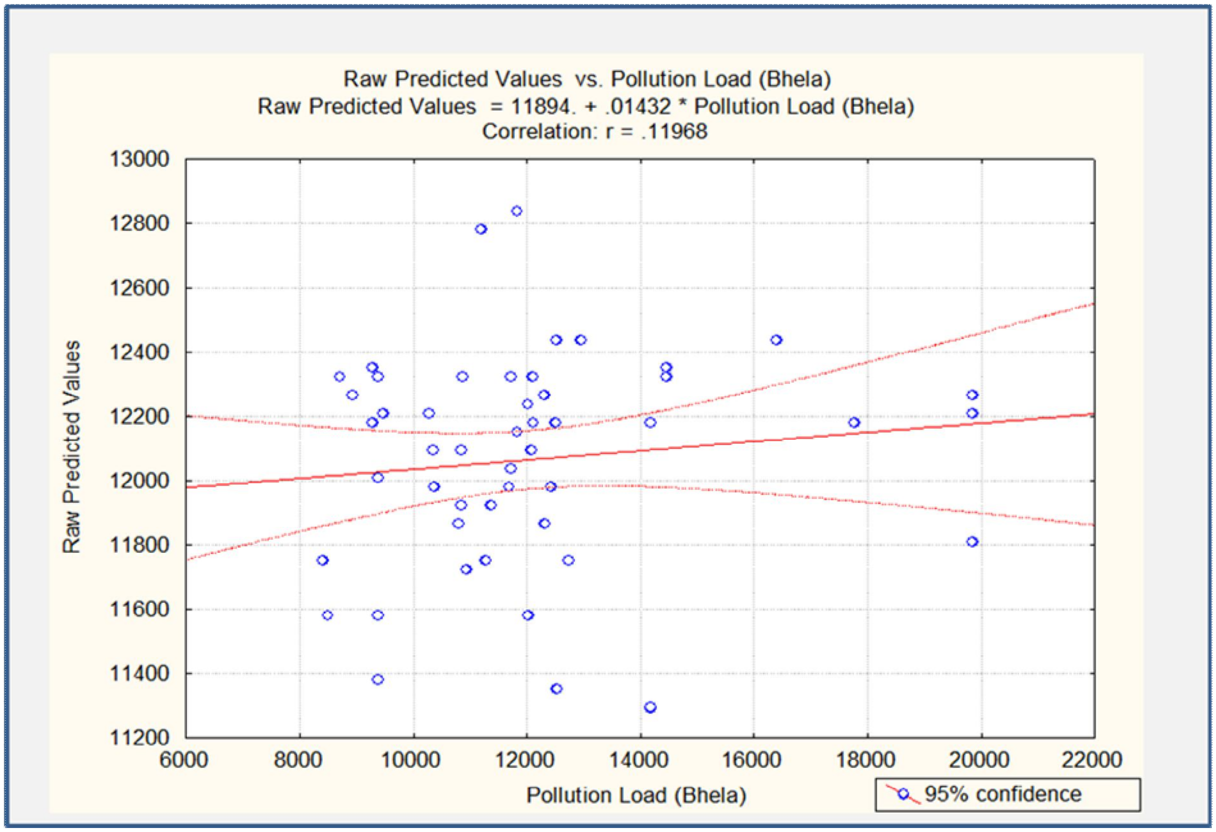


Fig 4.4.3 Prediction of pollution load in river Kosi

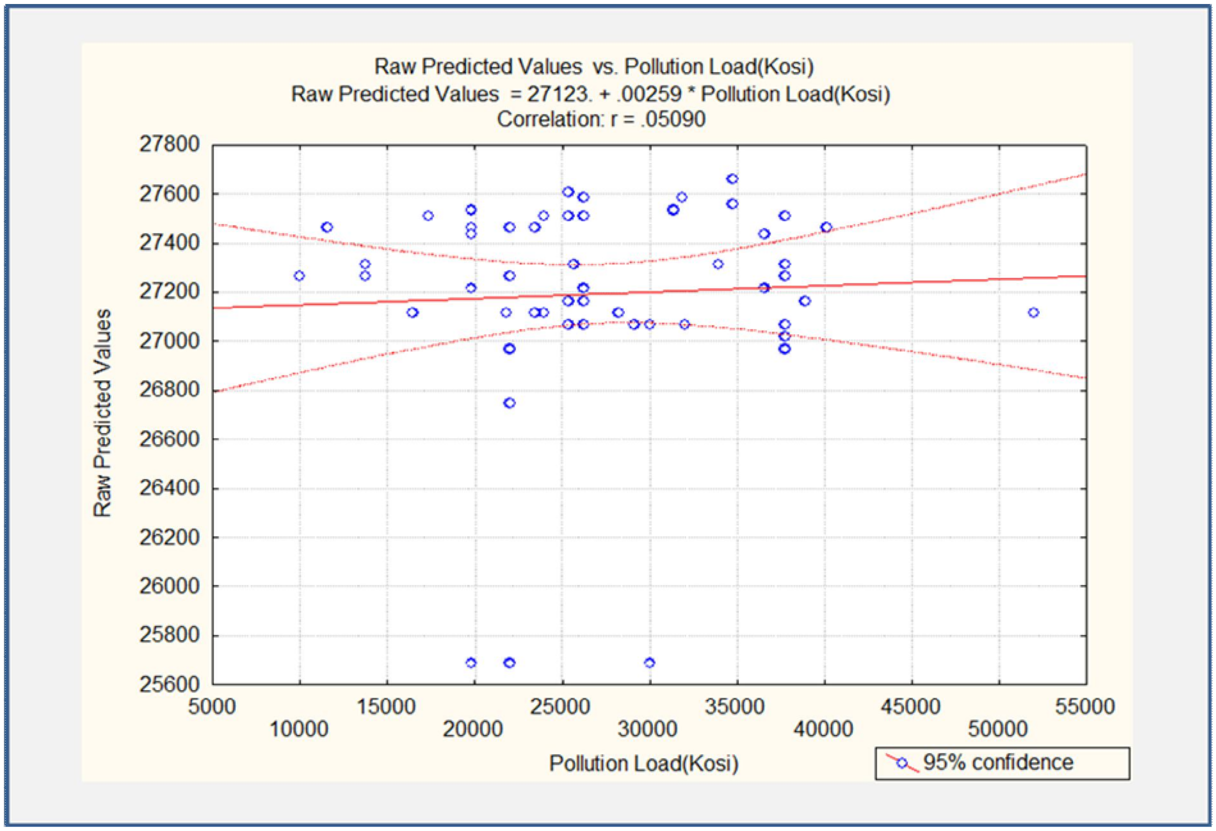
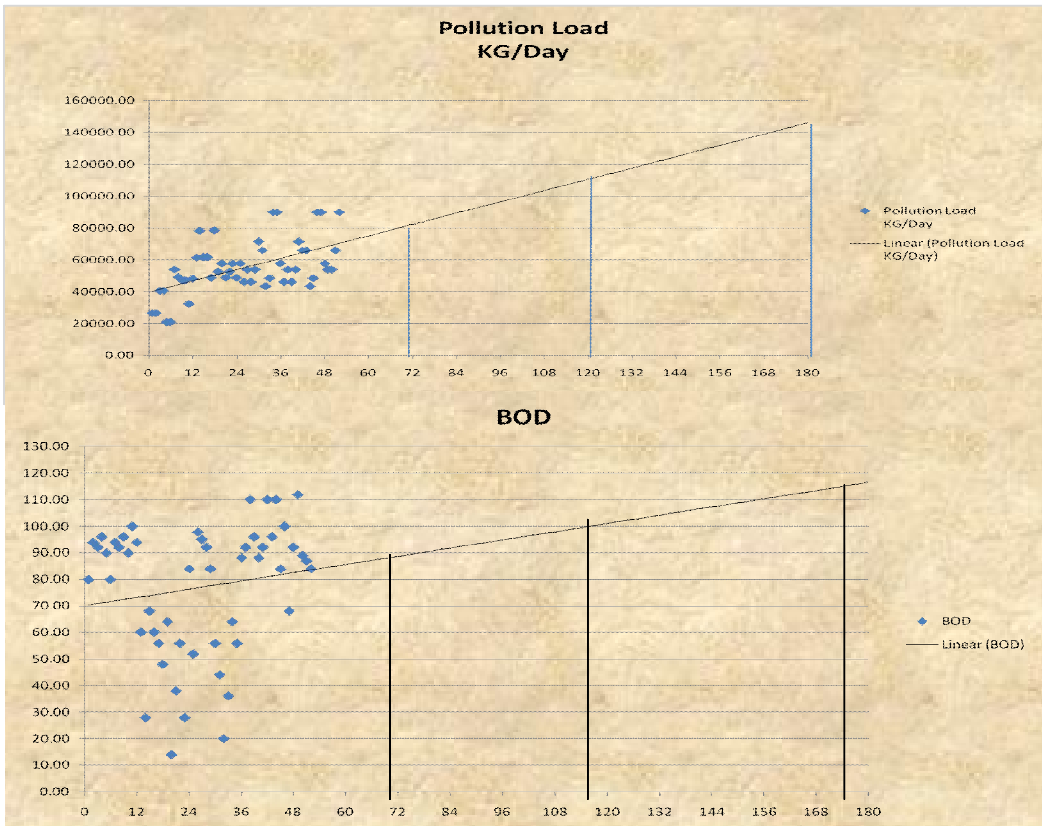


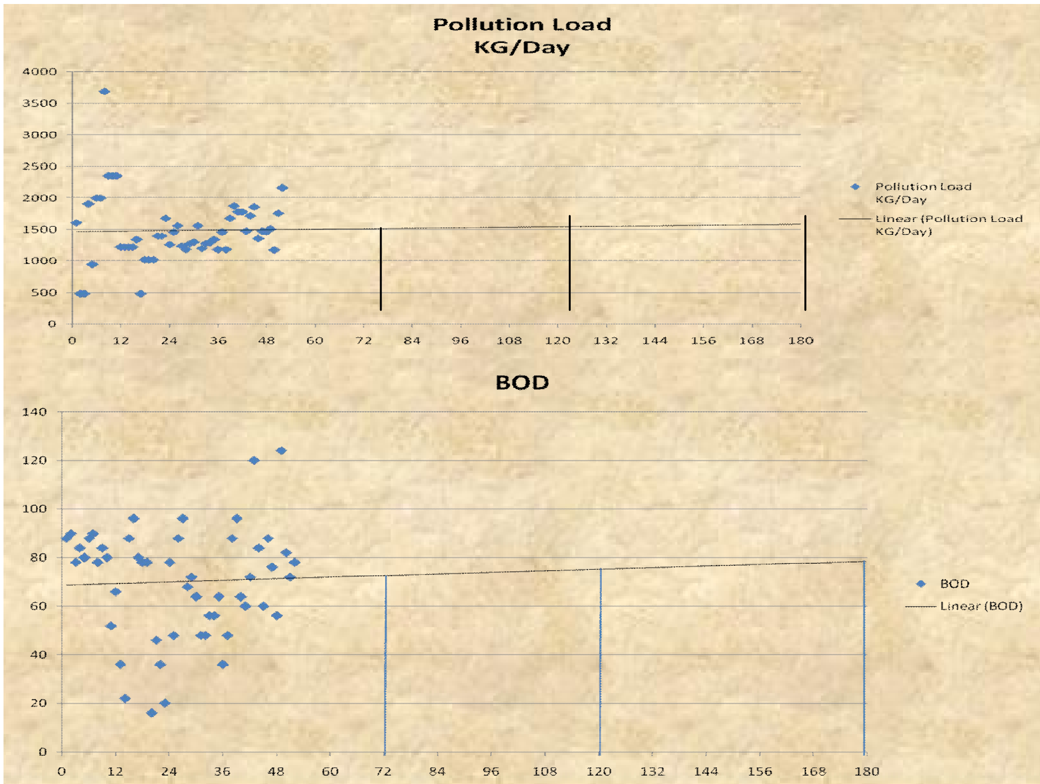
Fig 4.4.4 Trend of Pollution in River Dhela



X axis reveals months.

Y axis reveals values of Pollution load and BOD respectively

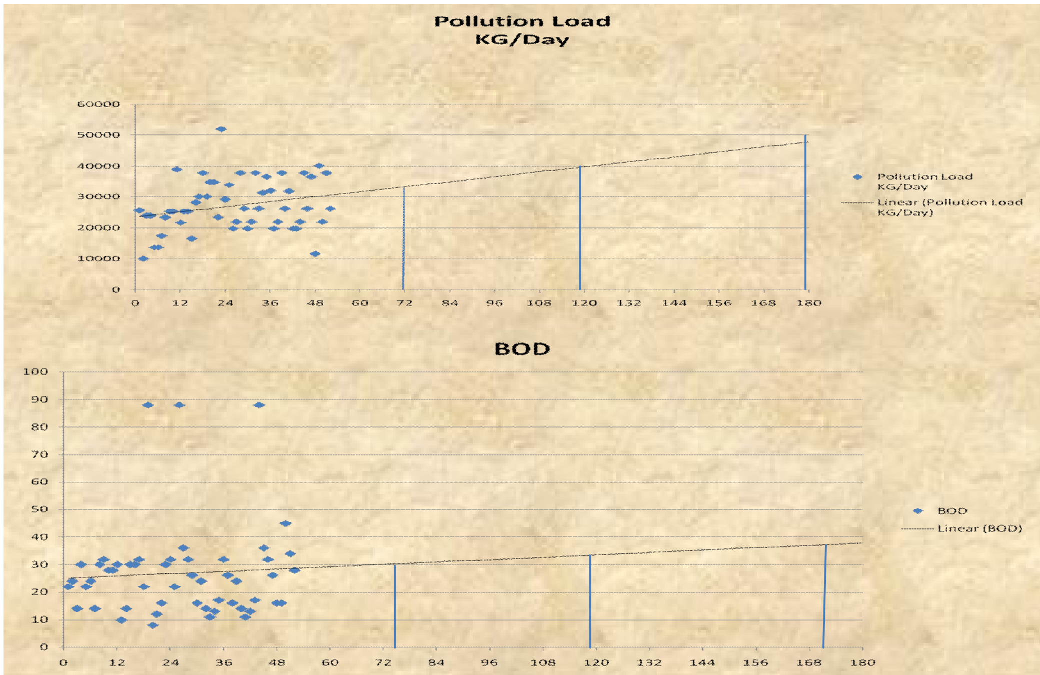
Fig 4.4.5 Trend of Pollution in River Bhela



X axis reveals months.

Y axis reveals values of Pollution load and BOD respectively

Fig 4.4.6 Trend of Pollution in River Kosi



X axis reveals months.

Y axis reveals values of Pollution load and BOD respectively

Table 4.4.1 Prediction of Pollution Load in Polluted Rivers

Name of the river	Pollution input into river in Kg/day			BOD in river in mg/l		
	Present	**2015**	**2020**	**Present**	**2015**	**2020**
River Dhela	60,000	110000	140000	80	100	115
River Bhela	1400	1500	1700	70	75	80
River Kosi	25000	40000	48000	25	35	40

4.5 APPLICATION OF ADVANCE EFFLUENT TREATMENT TECHNOLOGIES

From the review on pulp and paper industries waste water treatment, it is found that advance technologies such as membrane technology, fungal treatment and Activated sludge with ozonation are helpful in reducing the pollution load very significantly. These technologies were implied in lab to treated effluent of pulp and paper mill after conventional treatment. It is found that Membrane technology will reduce the organic load in effluent by 95%, Fungal treatment will reduce up to 57% and Activated sludge process with ozonation will reduce organic load up to 69% in the treated effluent. If these technologies will applied in all paper mills it will definitely reduce pollution load in the river and improve the river water quality in due course of time.

These three technologies have implied in the laboratory on pre treated waste water (treated through conventional treatment practice. Description of application is given as follows:

4.5.1 Experimental Setup For Membrane Filtration Technology

1. Treated waste water from conventional waste water treatment was passed through a membrane made of Polyurethene having pore size 1 micron.
2. Waste water was pushed into membrane so as to maintain a flow rate of 3 Lit/min.
3. Final re-treated waste water was analyzed for Biochemical oxygen demand.
4. Analysis was done every day evening for 21 days.
5. It is found that on an average Membrane filtration technology is helpful in reducing 95% of organic load in waste water if, applied after the conventional treatment.

4.5.2 Experimental Setup For Fungal Treatment

1. Treated waste water from conventional waste water treatment was passed thorough an artificial pond where suspension of fungi namely *Pleurotus ostreatus.*
2. Above suspension was added to artificial bed of sand and gravels and waste water was allowed to pass through it by gravity so as to maintain a retention time of 24 hrs.
3. Final re-treated waste water was analyzed for Biochemical oxygen demand.
4. Analysis was done every day evening for 21 days.
5. It is found that on an average Fungal treatment is helpful in reducing 56% of organic load in waste water if, applied after the conventional treatment.

4.5.3 Experimental Setup For Activated Sludge With Ozonation

1. This is an integrated treatment process and can be applied along with convention treatment process.
2. In the aerobic bioreactor (Activated sludge) total dose @ 1.4mg/l of Ozone was added. This is divided into 4 parts and added at the interval of 02 hours.
3. Final re-treated waste water was analyzed for Biochemical oxygen demand.
4. Analysis was done every day evening for 21 days.
5. It is found that on an average Activated sludge process with ozonation is helpful in reducing 67% of organic load in waste water if, applied after the conventional treatment.

Results obtained by applying these three advance technologies are presented in table 4.5.1. The results are statistically analyzed by applying paired‘t’ test. Calculation of paired t test is given in Appendix-3. From the analysis of paired t test it is concluded that the above three advance technologies, if applied to waste water treatment after conventional treatment will be quite efficient in waste water treatment. The statement is statistically proved at 95% level of confidence.

Table 4.5.1: Results of Effluent Quality after applying Advance Technologies and analysed by 't' test.

After conventional treatment BOD (mg/l)	Membrane Filtration	Fungal treatment	Activated Sludge with Ozonation
X	**A**	**B**	**C**
128	4.7	48.6	26
230	6.2	66.4	32.6
80	4.2	42.2	28.8
375	7.5	68.3	48.6
72	4.2	34.4	18.8
76	3.8	34.4	22.8
68	3.8	28.4	24.4
76	3.6	32.6	29.8
92	3.6	56.9	24.6
88	4.2	46.2	28.4
140	6.4	54.6	34.8
155	5.8	56.8	38.6
96	3.6	34.2	32.8
78	3.4	32.4	24.6
124	6.4	48.6	39.3
58	3.2	32.8	29.6
96	3.2	34.6	36.8
124	3.4	56.8	32.7
72	6.3	34.4	22.6
85	2.8	38.8	26.8
68	3.2	36.8	22.8
% Reduction	**95.5 %**	**56.7%**	**68.8%**
Std dev (in % reduction)	**1.4**	**9.8**	**8.5**

CHAPTER-5 CONCLUSION

From the above study it is concluded that rapid industrialization and urban development results in deterioration of water quality over the years. Rivers Ram Ganga River System is found more polluted compared to the other river systems because of industrial density resulted in discharge of huge effluent and discharge of untreated sewage. Stretch of river Ganga passing through Haridwar, and stretch of river Bhagirathi passing through Utttarkashi were also observed as another polluted stretch. Due to very less urbanization and industrial activities along the river Yamuna system in the Uttarakhand State, concentration of pollutants was found very less as compared to other river systems.

Distribution of pollutants at different site is presented in Table 5.1. Where it is clear that G-8, G-13, G-15, Y-3, Y-4, K-2, K-7, K-8 sites are found most contaminated.

5.1 MAJOR CONCLUSION

Fe in River Yamuna system and Zn in Kumaon rivers shows significant temporal variations at 90% LOS.

No significant difference in the temporal distribution of remaining metals is shown at 95% LOS.

All metals except Fe in River Yamuna System shows very significant variation in spatial distribution in different river systems at 95 % LOS.

Significant temporal variation in temperature in Ganga & Kumaon rivers, Turbidity and Total hardness in Yamuna, TDS in river Ganga and Phosphate in Kumaon rivers is shown at 95% LOS.

All physicochemical parameters show significant variation in spatial distribution in different river systems at 95 % LOS.

5.2 INTERRELATIONSHIP OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS

- Interrelationship of various physicochemical parameters has been carried out and following interrelationships **is not found correlated** at 95% LOS

  TSS with Cl, Na and K

  K with EC, Total hardness

  pH with Phosphate and Total hardness

  BOD with phosphate
- All **metals** showed **negative correlation with DO and pH** mean more organic load in the water bodies more will be the concentration of heavy metals because organic matter provide surface for lechation of metals in acidic conditions.
- **Metals** showed **positive correlation with Electrical Conductivity**. Higher concentration of TDS and TSS along with EC may be result of rock-bed interaction, higher sedimentation load due to high relief, tectonic disturbance and large scale human intervention result in high TDS and TSS and EC which simultaneously could be the region for positive correlation of EC with metals in the present study.
- All **metals** showed **positive correlation with each other** in the present study **except Zn interrelationship with Cu and Pb**. Lead showed strong positive correlation with Cu and Fe, where Cu and Fe itself strongly positive correlated.

5.3 PREDICTION OF POLLUTION LOAD IN DIFFERENT RIVERS AND RIVER WATER QUALITY

Data of pollution load has been complied since Jan 2006 to October 2010 and computed for next 10 years for trend analysis by using linear regressing analysis. This was applied in river Kosi, Dhela and Bhela which are found more polluted in the present study. it is predicted that the pollution load in river Dhela will go up to 140000Kg/day by year 2020, in river Bhela it will go up to 1700 Kg/day and in river Kosi pollution load will go up to 48000 Kg/day by the year 2020.

5.4 ADVANCE TECHNOLOGY FOR WASTE WATER TREATMENT

From the data collection on waste water characteristics it is found that pollution load in Kumaon rivers is due to discharge from Pulp and Paper Mills.

From the review on pulp and paper industries waste water treatment, it is found that advance technologies such **as membrane technology, fungal treatment and Activated sludge with ozonation** are helpful in reducing the pollution load very significantly while applying after conventional treatment.

It is found that **Membrane technology** will reduce the organic load in effluent by **95%**, **Fungal treatment** will reduce up to **57%** and **Activated sludge process with ozonation** will reduce organic load up to **69%.** If these technologies will applied in all paper mills it will definitely reduce pollution load in the river and improve the river water quality in due course of time.

Table 5.1 Distribution of pollutants having maximum concentrations amongst the sampling location during different seasons

Sampling Point	Jan-10	Apr-10	Jul-10	Oct-10
G1-G-7	Nil	Nil	Nil	Nil
G-8	PO4, TA, TDS, TSS, Na, K, EC, Cu, Fe	PO4, TA, TDS, TSS, Na, K, EC, Cu, Fe, Pb	PO4, TA, TDS, TSS, Na, K, EC, Cu, Fe	PO4, TA, TDS, TSS, K, EC, Cu, Pb
G-9	Nil	Na	Na	Na
G-10	Do, Cl, Na	DO, Cl, Na	Cl, Na	Cl, Na
G-11	Nil	Na	Nil	BOD, Cu
G-12	Nil	Nil	Turb	Fe
G-13	DO, BOD	TH, BOD	BOD	Fe
G-14	Nil	Zn	TH	TH, Fe, Zn
G-15	TH, Na, K, EC, Pb, Cu, Zn	PO4, TH, Na, K, Pb, Zn	EC, K, DO, Na, Pb, Fe, Zn	PO4, K, EC, DO, Fe, Pb
Y-1	Nil	Nil	Fe	Fe
Y-2	Cu	Nil	Fel, Turb	Nil
Y-3	Zn, Fe, Cu, Pb, TA	Zn, Fe, Cu, Pb, EC	Zn, Fe, Cu, Pb, TA	Zn, Fe, Cu, Pb, EC
Y-4	EC, Na, K, Cl, TSS, TDS, TH, PO4, BOD, DO	Fe, EC, Na, K, Cl, TSS, TDS, TH, PO4, BOD, DO	Fe, EC, Na, K, Cl, TSS, TDS, TH, PO4, BOD, DO	Zn, Fe, EC, Na, K, Cl, TSS, PO4, DO
Y-5	BOD	TA, BOD	Fe, TDS, BOD	TDS, TA, TH, BOD
K-1	K, Cu	DO, K, Cu	Cu	K
K-2	Cl, Na, K, Cu, Fe, Zn	DO, Cl, Na, K, Cu	Cl, Na, K, Cu, Zn	TH, Cl, Na, Cu
K-3	Cu, Fe	Pb, Clu, Fe	Cu, Fe, Zn	Pb, Cu, Fe
K-4	Cu	Pb, Cu, Fe	Cu	Cu
K-5	Nil	Nil	Nil	Nil
K-6	Nil	DO, BOD	DO	Nil
K-7	DO, BOD, TA, TDS, TSS, K, EC, Pb, Cu, Zn	DO, PO4, TA, TDS, TSS, K, EC, Pb, Cu, Zn	BOD, PO4, TH, TDS, EC, Pb, Cu	DO, BOD, TA, TDS, EC, Pb, Cu, Zn
K-8	DO, BOD, PO4, TH, TA, TSS, K, Pb, Cu, Zn	DO, PO4, TH, TA, TSS, K, Pb, Cu, Zn	PO4, TH, TA, TSS, K, Pb, Cu	PO4, TSS, K, Pb, Cu, Zn

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Appendix-I

Calculation of ANNOVA for Spatial and temporal variation.

(Referring an example of Pb)

ANOVA Pb in River Ganga System (Spatial Variation)

H0 : $\mu_{JG1} = \mu_{G2} = \mu_{G3}$ ------=------ μ_{G15} i.e. **There is no significant spatial variation of Pb concentration in river Ganga System**

H1 : : $\mu_{G1} \neq \mu_{G2} \neq \mu_{G3}$ ------ ≠------- μ_{G15} i.e Significant spatial variation of Pb concentration in river Ganga System has been observed

Here **Fcrit<F** at 95% level of confidence and hence **reject** H0 i.e alternate hypothesis H1 is accepted. It means significant difference of Pb concentration at various sampling locations in River Ganga System.

ANOVA (LOS 95%) **Spatial Variations (Different sites along river Ganga)**						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.544	14	0.253128	18.11569	5.35E-14	1.918249
Within Groups	0.629	45	0.013973			
Total	4.173	59				

Here **Fcrit > F** at 95% level of confidence and hence **do not reject H0**. It means there is no significant difference of Pb concentration in river Ganga system during different seasons.

Appendix-II

Pollution Load and River Water Quality from 2006 to 2010.

River Dhela

Month	Industrial waste Characteristics			Discharge kld	Pollution Load KG/Day	River quality		
	pH	TDS	BOD			pH	TDS	BOD
Jan-06	6.60	902.50	28.50	28450.00	**26486.95**	7.87	1400.00	80.00
Feb-06	6.60	902.50	28.50	28450.00	**26486.95**	7.97	1303.00	94.00
Mar-06	6.62	1170.00	256.80	28450.00	**40592.46**	7.94	1043.00	92.00
Apr-06	6.62	1170.00	256.80	28450.00	**40592.46**	7.47	1198.00	96.00
May-06	6.92	657.00	80.00	28450.00	**20967.65**	7.42	1069.00	90.00
Jun-06	6.92	657.00	80.00	28450.00	**20967.65**	7.87	1400.00	80.00
Jul-06	6.94	1587.00	312.00	28450.00	**54026.55**	7.97	1303.00	94.00
Aug-06	6.70	1374.33	346.67	28450.00	**48962.45**	7.94	1043.00	92.00
Sep-06	6.14	1428.33	228.33	28450.00	**47132.17**	7.47	1198.00	96.00
Oct-06	6.14	1428.33	228.33	28450.00	**47132.17**	7.42	1069.00	90.00
Nov-06	7.03	1046.33	91.83	28450.00	**32380.51**	7.93	1334.00	100.00
Dec-06	6.89	905.50	89.50	48500.00	**48257.50**	6.69	1221.00	94.00
Jan-07	6.65	1172.00	97.33	48500.00	**61562.67**	7.29	712.00	60.00
Feb-07	7.26	1424.00	190.00	48500.00	**78279.00**	7.29	569.00	28.00
Mar-07	6.67	1208.00	65.00	48500.00	**61740.50**	7.51	726.00	68.00
Apr-07	6.67	1208.00	65.00	48500.00	**61740.50**	6.93	935.00	60.00
May-07	7.33	952.00	52.00	48500.00	**48694.00**	6.67	947.00	56.00

Jun-07	6.90	1488.00	134.00	48500.00	**78667.00**	6.70	984.00	48.00
Jul-07	7.25	925.00	70.67	52900.00	**52670.77**	6.94	1191.00	64.00
Aug-07	7.05	1020.33	72.00	52900.00	**57784.43**	7.07	438.00	14.00
Sep-07	7.38	837.67	86.00	52900.00	**48861.97**	6.92	564.00	38.00
Oct-07	7.25	925.00	70.67	52900.00	**52670.77**	7.24	661.00	56.00
Nov-07	7.05	1020.33	72.00	52900.00	**57784.43**	7.32	549.00	28.00
Dec-07	7.38	837.67	86.00	52900.00	**48861.97**	7.08	626.00	84.00
Jan-08	7.19	985.00	109.60	52900.00	**57904.34**	7.34	680.00	52.00
Feb-08	8.31	844.00	29.00	52900.00	**46181.70**	7.48	764.00	98.00
Mar-08	6.67	958.67	60.17	52900.00	**53896.28**	7.49	958.00	95.00
Apr-08	8.31	844.00	29.00	52900.00	**46181.70**	7.62	1019.00	92.00
May-08	6.67	958.67	60.17	52900.00	**53896.28**	7.41	919.00	84.00
Jun-08	6.58	1200.00	150.00	52900.00	**71415.00**	7.14	962.00	56.00
Jul-08	6.21	1137.00	112.00	52900.00	**66072.10**	7.33	663.00	44.00
Aug-08	6.93	786.50	34.50	52900.00	**43430.90**	7.54	564.00	20.00
Sep-08	7.11	856.33	61.00	52900.00	**48526.93**	7.44	648.00	36.00
Oct-08	7.57	1497.75	202.50	52900.00	**89943.23**	6.97	630.00	64.00
Nov-08	7.57	1497.75	202.50	52900.00	**89943.23**	6.91	549.00	56.00
Dec-08	7.19	985.00	109.60	52900.00	**57904.34**	7.45	1043.00	88.00
Jan-09	8.31	844.00	29.00	52900.00	**46181.70**	7.11	1127.00	92.00
Feb-09	6.67	958.67	60.17	52900.00	**53896.28**	7.30	1378.00	110.00
Mar-09	8.31	844.00	29.00	52900.00	**46181.70**	6.94	1029.00	96.00
Apr-09	6.67	958.67	60.17	52900.00	**53896.28**	7.45	1043.00	88.00
May-09	6.58	1200.00	150.00	52900.00	**71415.00**	7.11	1127.00	92.00

Jun-09	6.21	1137.00	112.00	52900.00	**66072.10**	7.30	1378.00	110.00
Jul-09	7.20	1176.00	71.00	52900.00	**65966.30**	6.94	1029.00	96.00
Aug-09	6.93	786.50	34.50	52900.00	**43430.90**	7.33	781.00	110.00
Sep-09	7.11	856.33	61.00	52900.00	**48526.93**	7.49	784.00	84.00
Oct-09	7.57	1497.75	202.50	52900.00	**89943.23**	6.88	1086.00	100.00
Nov-09	7.57	1497.75	202.50	52900.00	**89943.23**	7.14	713.00	68.00
Dec-09	7.19	985.00	109.60	52900.00	**57904.34**	7.11	1127.00	92.00
Jan-10	6.90	963.00	55.00	52900.00	**53852.20**	7.50	1650.00	112.00
Apr-10	6.67	958.67	60.17	52900.00	**53896.28**	6.90	1766.00	89.00
Jul-10	7.20	1176.00	71.00	52900.00	**65966.30**	7.50	2254.00	87.00
Oct-10	7.57	1497.75	202.50	52900.00	**89943.23**	7.20	2634.00	84.00

Pollution Load and River Water Quality from 2006 to 2010.

River Bhela

Month	Industrial characteristics			Discharge kld	Pollution Load KG/Day	River quality		
	pH	TDS	BOD			pH	TDS	BOD
Jan-06	6.7	710	161	10000	**8710**	7.08	1008	88
Feb-06	6.5	880	48	10000	**9280**	7.03	1260	90
Mar-06	6.5	880	48	10000	**9280**	7.86	722	78
Apr-06	6.4	1040	191	10000	**12310**	7.55	926	84
May-06	6.9975	933.75	94.5	10000	**10282.5**	7.07	938	80
Jun-06	6.813333	1246	200	10000	**14460**	7.08	1008	88
Jul-06	6.813333	1246	200	10000	**14460**	7.03	1260	90
Aug-06	6.735	1408	369	10000	**17770**	7.86	722	78
Sep-06	7.275	1750	235	10000	**19850**	7.55	926	84
Oct-06	7.275	1750	235	10000	**19850**	7.07	938	80
Nov-06	7.275	1750	235	10000	**19850**	7.97	455	52
Dec-06	6.845	816	122	10000	**9380**	7.59	1154	66
Jan-07	6.845	816	122	10000	**9380**	7.13	366	36
Feb-07	6.845	816	122	10000	**9380**	7.08	274	22
Mar-07	6.845	816	122	10000	**9380**	6.99	862	88
Apr-07	6.34	1505.3	134	10000	**16393.3**	6.72	1146	96
May-07	6.61	899	48	10000	**9470**	6.56	1660	80
Jun-07	6.445	1316.5	102	10000	**14185**	6.74	1186	78

Jul-07	6.445	1316.5	102	10000	**14185**	6.91	935	78
Aug-07	6.445	1316.5	102	10000	**14185**	6.98	371	16
Sep-07	6.92	953.6667	140	10000	**10936.66667**	7.16	527	46
Oct-07	7.055	709.5	140	10000	**8495**	7.06	521	36
Nov-07	6.84	1085	168	10000	**12530**	7.11	366	20
Dec-07	6.84	1085	126	10000	**12110**	6.98	586	78
Jan-08	7.22	1128	146	10000	**12740**	6.88	458	48
Feb-08	6.705	1054.5	156	10000	**12105**	7.08	540	88
Mar-08	7.22	1128	124	10000	**12520**	7.19	1061	96
Apr-08	6.705	1054.5	118	10000	**11725**	7.1	694	68
May-08	6.736667	907	128	10000	**10350**	7.06	727	72
Jun-08	6.736667	907	130	10000	**10370**	6.86	1061	64
Jul-08	6.64	972	156	10000	**11280**	6.51	578	48
Aug-08	7.06	721	120	10000	**8410**	7.09	497	48
Sep-08	7.256667	951.6667	128	10000	**10796.66667**	6.9	559	56
Oct-08	7.256667	951.6667	129	10000	**10806.66667**	7.22	701	56
Nov-08	7.11	1035	134	10000	**11690**	7.06	473	64
Dec-08	6.84	1085	118	10000	**12030**	7.36	587	36
Jan-09	7.22	1128	146	10000	**12740**	6.88	458	48
Feb-09	6.705	1054.5	118	10000	**11725**	7.08	540	88
Mar-09	7.22	1128	168	10000	**12960**	7.19	1061	96
Apr-09	6.705	1054.5	188	10000	**12425**	6.88	337	64
May-09	6.736667	907	178	10000	**10850**	6.95	889	60
Jun-09	6.736667	907	178	10000	**10850**	7.09	1077	72

Jul-09	6.64	972	148	10000	**11200**	7.32	1241	120
Aug-09	7.06	721	172	10000	**8930**	6.69	817	84
Sep-09	7.256667	951.6667	186	10000	**11376.66667**	7.23	649	60
Oct-09	7.256667	951.6667	136	10000	**10876.66667**	7.34	767	88
Nov-09	7.11	1035	148	10000	**11830**	7.41	524	76
Dec-09	6.84	1085	147	10000	**12320**	7.06	473	56
Jan-10		1032	151	10000	**11830**	7.5	915	124
Apr-10		1085	117	10000	**12020**	7.5	1218	82
Jul-10		1032	176	10000	**12080**	7.2	1354	72
Oct-10		1035	216	10000	**12510**	7.4	1488	78

Pollution Load and River Water Quality from 2006 to 2010.

River Kosi

Month	Industrial characteristics			Discharge kld	Pollution Load KG/Day	River quality		
	pH	TDS	BOD			pH	TDS	BOD
Jan-06	5.73	1160.00	191.67	19000	**25682**	7.64	750	22
Feb-06	7.20	480.00	45.00	19000	**9975**	7.56	708	24
Mar-06	6.80	1215.00	46.50	19000	**23969**	7.53	557	14
Apr-06	6.80	1215.00	46.50	19000	**23969**	7.11	461	25
May-06	7.64	660.00	63.00	19000	**13737**	7.64	750	22
Jun-06	7.64	660.00	63.00	19000	**13737**	7.56	708	24
Jul-06	6.92	850.00	63.00	19000	**17347**	7.53	557	14
Aug-06	6.87	1207.50	26.50	19000	**23446**	7.11	461	30
Sep-06	6.84	1199.50	136.50	19000	**25384**	7.29	516	32
Oct-06	6.84	1199.50	136.50	19000	**25384**	7.33	538	28
Nov-06	6.92	1928.00	120.00	19000	**38912**	7.63	434	52
Dec-06	7.32	1055.00	92.00	19000	**21793**	6.96	462	30
Jan-07	7.04	1220.00	116.00	19000	**25384**	7.86	357	24
Feb-07	7.04	1220.00	116.00	19000	**25384**	7.44	331	41
Mar-07	7.54	841.00	26.00	19000	**16473**	7.12	448	30
Apr-07	6.45	1329.00	157.33	19000	**28240**	7.12	448	30
May-07	6.26	1098.00	84.00	25400	**30023**	7.59	607	32
Jun-07	6.45	1329.00	157.33	25400	**37753**	7.88	591	22
Jul-07	6.26	1098.00	84.00	25400	**30023**	7.52	910	64

Aug-07	6.60	1239.00	130.00	25400	**34773**	7.48	377	42
Sep-07	6.60	1239.00	130.00	25400	**34773**	7.34	539	42
Oct-07	6.65	856.00	67.00	25400	**23444**	7.46	484	41
Nov-07	6.92	1928.00	120.00	25400	**52019**	7.12	448	30
Dec-07	7.32	1055.00	92.00	25400	**29134**	7.59	607	32
Jan-08	7.04	1220.00	116.00	25400	**33934**	7.88	591	52
Feb-08	7.81	752.00	116.00	25400	**22047**	7.52	910	42
Mar-08	7.54	841.00	157.00	25400	**25349**	7.51	695	36
Apr-08	6.45	1329.00	157.33	25400	**37753**	7.37	656	32
May-08	6.09	969.00	64.00	25400	**26238**	7.45	584	26
Jun-08	7.81	752.00	164.00	25400	**23266**	7.24	603	16
Jul-08	7.54	841.00	142.00	25400	**24968**	7.19	637	24
Aug-08	6.45	1329.00	157.33	25400	**37753**	7.52	463	14
Sep-08	6.09	969.00	167.00	25400	**28854**	7.4	414	32
Oct-08	6.87	1139.00	97.00	25400	**31394**	7.21	405	46
Nov-08	6.93	1311.00	130.00	25400	**36601**	7.35	427	41
Dec-08		1157.50	104.00	25400	**32042**	7.37	656	32
Jan-09		752.00	143.00	25400	**22733**	7.45	584	26
Feb-09		841.00	128.00	25400	**24613**	7.24	603	32
Mar-09		1329.00	157.33	25400	**37753**	7.19	637	24
Apr-09		969.00	64.00	25400	**26238**	7.52	463	14
May-09		1135.50	120.00	25400	**31890**	7.4	414	22
Jun-09		752.00	136.00	25400	**22555**	7.21	405	13
Jul-09		752.00	142.00	25400	**22708**	7.35	427	42

Aug-09		841.00	139.00	25400	**24892**	7.52	910	88
Sep-09		1329.00	157.33	25400	**37753**	7.51	695	63
Oct-09		969.00	64.00	25400	**26238**	7.37	656	32
Nov-09		1311.00	130.00	25400	**36601**	7.45	584	26
Dec-09		427.00	132.00	25400	**14199**	7.24	603	16
Jan-10		1467.00	126.00	25400	**40462**	7.20		16
Apr-10		841.00	126.00	25400	**24562**	7.6		45
Jul-10		1329.00	157.33	25400	**37753**	6.8		34
Oct-10		969.00	64.00	25400	**26238**	7.1		28

Appendix-III

Calculation of Paired t-test amongst the treated waste water quality after conventional treatment (say X) and by adopting 03 modern technologies A,B,C (A– membrane filtration B-fungal treatment, C-Activated sludge with ozonation)

Case 1

Ho : µX = µA i.e.

There is no significance difference between conventional treatment process and membrane filtration technology

H1 : µX > µA

df = (20-1) = 20

t_{cal} = 7.045

t_{tab}= 1.724 (LOS 95 %)

Here t_{cal} > t_{tab}

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	113.381	4.452381
Variance	5160.348	1.904619
Observations	21	21
Pearson Correlation	0.717167	
Hypothesized Mean Difference	0	
df	20	
t Stat	7.045264	
P(T<=t) one-tail	3.92E-07	
t Critical one-tail	1.724718	
P(T<=t) two-tail	7.83E-07	
t Critical two-tail	2.085963	

Hence null Hypothesis is rejected at 95% level of significance i.e. alternate hypothesis is accepted. Membrane filtration technology is quite efficient. Statement is made at 95% of confidence level.

Case 2 **Ho : µX = µB i.e** **There is no significance difference between conventional treatment process and Fungal treatment)** **H1 : µX > µB** **df = (20-1) = 20** **t_{cal} = 5.096** **t_{tab}= 1.724 (LOS 95 %)** **Here $t_{cal} > t_{tab}$**	

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	113.381	43.77143
Variance	5160.348	146.0541
Observations	21	21
Pearson Correlation	0.800039	
Hypothesized Mean Difference	0	
df	20	
t Stat	5.096658	
P(T<=t) one-tail	2.75E-05	
t Critical one-tail	1.724718	
P(T<=t) two-tail	5.51E-05	
t Critical two-tail	2.085963	

Hence null Hypothesis is rejected at 95% level of significance and alternate hypothesis is accepted. Application of fungal treatment to the effluent is quite efficient in reducing the BOD load. Statement is made at 95% of confidence level.

Case 3	t-Test: Paired Two Sample for Means		
Ho : μX = μC i.e		*Variable 1*	*Variable 2*
There is no significance difference between conventional treatment process and activated sludge process with ozonation)	Mean	113.381	29.81905
	Variance	5160.348	50.04462
	Observations	21	21
H1 : μX > μC	Pearson Correlation	0.756074	
df = (20-1) = 20	Hypothesized Mean Difference	0	
t_{cal} = 5.74	df	20	
	t Stat	5.745546	
t_{tab}= 1.724 (LOS 95 %)	P(T<=t) one-tail	6.36E-06	
	t Critical one-tail	1.724718	
Here $t_{cal} > t_{tab}$	P(T<=t) two-tail	1.27E-05	
	t Critical two-tail	2.085963	

Hence null Hypothesis is rejected at 95% level of confidence and alternate hypothesis is accepted. Activated sludge process with ozonation technology is quite efficient. Statement is made at 99.5% of confidence level.

CURRICULUM VITAE

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3. Worked as Junior Research Fellow at Department of Environmental Science and Engineering, Guru Jambeshwar University of Science and Technology, Hissar, Haryana.

II Educational Qualification:

1. Matric and Senior Secondary from KLDAV Inter College (U.P. Board) Roorkee in 1993 and 1995 respectively.
2. Graduation in Science with Environmental Science as a specialized subject from Kurukshetra University in 1998.
3. Post Graduation in Science (Environmental Sciences) from Guru Jambeshwar University of Science and Technology, Hissar, Haryana in 2000.

III Professional Qualification:

1. M. Tech. in Environmental Science and Engineering from Guru Jambeshwar University of Science and Technology, Hissar, Haryana in 2001
2. Qualified UGC NET with JRF in Environmental Science during June 2000.
3. Certificate Course: NEBOSH-IGC (National Examination Board on Occupational Safety and Health International general Certificate) by Government of U.K.

IV Professional Training:

1. One month training in Mathura Oil Refinery on Pollution Control measures and environment management
2. Two months training in Physical Research Laboratory, Ahembdabad on Aspects of Hydrocarbons in the Atmosphere.
3. Short term training on Hazardous Waste Management in Administrative Staff College of India, Hyderabad and at Environment Protection and Training research Institute (EPTRI), Hyderabad.

V List of Publications:

1. "Defluoridation of ground water using brick powder as an adsorbent" **published** in Journal of Hazardous Materials: B128, 289-293, 2006. Elsevier Publication.
2. "Determination of exposure and probable ingestion of fluoride through tea, toothpaste, tobacco and pan masala" **published** in Journal of Hazardous Materials: 142 (1-2), 77-80, 2007. Elsevier Publication.
3. "Suitability assessment of groundwater in some villages of Rewari District in Haryana" **published** in Journal of Environmental Monitoring and Assessment: 145 (1-3), 397-406, 2008. Springer Publication.
4. "Heavy metal contamination of river Yamuna, Haryana, India: Assessment by metal enrichment factor of the sediments" **published** in Journal of Hazardous Materials: 164 (1), 265-270, 2009. Elsevier Publication.
5. "Sources and Reactivity of NMHCs and VOCs in Atmosphere: A review" **published** in Journal of Hazardous Materials: 166 (1), 17-26, 2009. Elsevier Publication.

List of Publication during Ph.D.

1. "Waste water treatment of pulp and paper industry: A review" **published** in Journal of Environment Science and Engineering: 53 (2), 203-218, April 2011. Journal published by National Environment Engineering Research Institute (NEERI).
2. "Deterioration of water quality of some eco-efficient Himalayan Rivers in India" **published** in International Journal of Environmental rehabilitation and Conservation: II (1), 29-49, 2011. ESSENCE Publication.
3. "Assessment of heavy metals and their interrelationships with some physicochemical parameters in eco-efficient rivers of Himalayan region" submitted in Journal of Environment Monitoring and Assessment. **Status is under review**.