Bacterial indicators of faecal pollution and physiochemical assessment of important North Indian lakes

Bakterijski indikatorji fekalnega onesnaženja in fizikalno-kemijsko stanje pomembnih jezer v severni Indiji

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Abstract: A study was conducted to investigate the water quality of seven important lakes in North India during the periods of summer, monsoon and winter seasons. All of these studied lakes are important recreational spots of India. Water samples were analyzed for various bacteriological parameters including total viable count (TVC), total coliform (TC), faecal coliform (FC) and faecal streptococci (FS). Also physico-chemical parameters like pH, conductivity, total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) were assessed. Total viable count exceeded the maximum permissible limits in all the lakes irrespective to different seasons. The high most probable number (MPN) values and presence of faecal coliforms and streptococci in the water samples suggests the potential presence of pathogenic microorganisms which might cause water borne diseases. A direct effect of season and human activities on the pollution status was ob-

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served in all the lakes. The over all objective of this work was to investigate the incidence of these indicator organisms, coliform, faecal coliform, faecal streptococci and physiochemical parameters during different seasons in important north Indian lakes.

Povzetek: V članku so predstavljeni rezultati raziskave kakovosti vode sedmih pomembnih jezer v severni Indiji, ki so potekale v poletnem, monsunskem in zimskem času. Vsa raziskana jezera predstavljajo pomembna rekreacijska območja v Indiji. V vzorcih vode so bili določeni različni bakteriološki parametri, kot so število bakterijskih kolonij (TVC), skupni koliformi (TC), fekalni koliformi (FC) in fekalni streptokoki (FS), določeni pa so bili tudi fizikalno-kemijski parametri kot so pH, električna prevodnost, celotna suspendirana snov (TDS), raztopljeni kisik (DO), biokemijska potreba po kisiku (BOD) in kemijska potreba po kisiku (COD). Število bakterijskih kolonij presega maksimalne dovoljene vrednosti v vseh jezerih v vseh opazovanih obdobjih. Visoko najbolj verjetno število bakterij (MPN) in prisotnost fekalnih koliformov in streptokokov v vzorcih vode nakazujejo potencialno prisotnost patogenih mikroorganizmov, ki lahko povzročijo obolenja. Tudi neposredni učinek sezon in človeške dejavnosti na stanje onesnaženja je bil opažen v vseh jezerih. Glavni namen opravljenih raziskav je bil določiti obseg indikatorskih organizmov, koliformov, fekalnih koliformov in fekalnih streptokokov ter spreminjanje fizikalno-kemijskih parametrov v različnimi letnih časih v pomembnih jezerih v severni Indiji.

Key words: coliforms, seasons, physiochemical, lake water, India
Ključne besede: koliformi, sezone, fizikalno-kemijski, jezerska voda, Indija

Introduction

India is rich in surface water resources. Nearly 80 % of rural residents rely on untreated ground water for potable water supplies. Rivers and lakes are the major sources of fresh water supply, but almost 70 % of India's surface water resources and ground water reserves have been contaminated (Rao & Mamatha, 2004).

Lake Riwalsar is eutrophic in nature and is situated in lesser Himalayas, surrounded by middle Shivalik rocks with a catchments area of 4.8 km^2, the surface area is 0.5 km^2 with maximum depth of 6.5 m. The lake Parashar is a high altitude lake with a catchment area of 8.9 km^2; the surface area is 0.23 km^2 with a maximum depth of 5.3 m. The Sukhna Lake is at the foot hills of Shivalik hills, the surface area is 3.0 km^2, the maximum depth is 9 m and catchments area is 14.9 km^2. The water flowing into the lake is heavily loaded with silt. Dul Lake is eutrophic in nature at foot hills of Himalayan range, which surrounds it on three sides. The catchments area is 316 km^2; surface area being 18 km^2 with maximum depth of 6 m. Lake Nainital is also eutrophic, a high altitude lake, situated in a valley surrounded by low and high hills. The total length of the drainage basin is about 42 km and lake has a catchments area of 11.8 km^2. The lake receives rain water and waste water from 24 permanent and temporary inlets coming from different sources and inhabited areas. The area of the lake is 0.46 km^2 and maximum depth is 26 m. The Bhimtal Lake is surrounded by high hills, with a catchments area of 12.3 km^2 and the surface area of the lake is 0.42 km^2. Maximum depth of the lake is 24.7 m and is of eutrophic nature. Lake Naukuchiatal is also surrounded by Himalayan hills. The lake has catchments area of 14.8 km^2, the surface area being 0.90 km^2 and maximum depth is 41.2 m and is of eutrophic nature (Central Water Commission, 2007).

In sub rural areas, water of lakes or ponds is sufficient to fulfill the water requirements of that area. In the present study, we collected water samples from important lakes of North India and examined to understand the outcome of seasonal variations on water quality. These lakes have different meanings to different people because they serve with different functions, such as drinking water to area residents nearby, recreation value, food protection for downstream residents, habitat for wild life, irrigation and water power generation. Some of these lakes are considered to be sacred. However, human activities have affected the water quality of the lakes. This type of eutrophication is called as 'cultural' eutrophication. The human activities include religious activities, tourism, bathing, washing, open defecation, cultivation, stone crushing, road construction, fishing, surface drainage, irrigation, drinking water uptake, rafting, discharges of industrial wastes and domestic wastewaters, and other similar activities.

Microorganisms are widely distributed in nature, and their abundance and diversity may be used as an indicator for the suitability of water (Okpokwasili & Akujobi, 1996). The use of bacteria as water quality indicators can be viewed in two ways, first, the presence of such bacteria can be taken as an indication of faecal contamination of the water and thus as a signal to determine why such contamination is present, how serious it is and what steps can be taken to eliminate it; second, their presence can be taken as an indication of the potential danger of health risks that faecal contamination posses. The higher the level of indicator bacteria, the higher the level of faecal contamination and the greater the risk of water-borne diseases (PIPES, 1981). A wide range of pathogenic microorganisms can be transmitted to humans via water contaminated with faecal material. These include enteropathogenic agents such as salmonellas, shigellas, enteroviruses, and multicellular parasites as well as opportunistic pathogens like Pseudomonas aeroginosa, Klebsiella, Vibrio parahaemolyticus and Aeromonas hydrophila (Hodegkiss, 1988). It is not practicable to test water for all these organisms, because the isolation and identification of many of these is seldom quantitative and extremely complicated (CAIRNEROSS et al., 1980; World Health Organization (WHO), 1983). An indirect approach is based on assumption that the estimation of groups of normal enteric organisms will indicate the level of faecal contamination of the water supply (WHO, 1983). The most widely used indicators are the coliform bacteria, which may be the total coliform that got narrowed down to the faecal coliforms and the faecal streptococci (KISTEMANN et al., 2002; PATHAK & GOPAL, 2001; HARWOOD et al., 2001). Concurrently, contamination of water by enteric pathogens has increased worldwide (ISLAM et al., 2001; PATHAK et al., 1991; CRAUN, 1986). However, to the best of our knowledge, no report is available on the bacterial as well as physiochemical parameters analysis of seven important lakes in North India. The overall objective of this work was to investigate the incidence of these indicator organisms, coliforms, faecal coliforms and faecal streptococci in relation with physiochemical parameters of north Indian lakes in different seasons.

MATERIALS AND METHODS

Collection of water samples

The lakes of the North Indian region were intensively surveyed to select different sites for sample collection from various lakes. Seven North Indian lakes which are renowned for recreational and tourism activities were selected (Table 1, Figure 1). Access to the individual sites was accomplished by way of boat. All the samples were collected just below the surface of lake water by plunging the open end of each sterile bottle before turning it upright to fill. Samples were collected during the summer, monsoon and winter seasons. Each lake was divided into four sampling sites and samples were collected in triplicate from each site, and were transported in ice boxes at 3 °C and brought to the laboratory for analysis (SOOD et al., 2008). The results presented in the tables are average of all the four sites of a particular lake.

Table 1. Lakes of North India selected in the study

Lake	**State**	**Altitude** (from sea level)	**Latitude and longitude**	**Significance**
Riwalsar	Himachal Pradesh	754 m	30° 15' N 77° 50' E	Tourism, Religious
Prashar	Himachal Pradesh	754 m	30° 12' N 77° 47' E	Tourism, Religious
Sukhna	Punjab and Haryana	365 m	30° 50' N 76° 48' E	Tourism, Recreational
Dul	Jammu and Kashmir	1583 m	34° 18' N 74° 91' E	Tourism, Recreational
Nanital	Uttarakhand	1938 m	29° 34' N 79° 23' E	Tourism, Recreational, Irrigation, Drinking
Bhimtal	Uttarakhand	1371.6 m	29° 21' N 79° 34' E	Tourism, Recreational
Naukuchiatal	Uttarakhand	1219 m	29° 32' N 79° 21' E	Tourism, Recreational

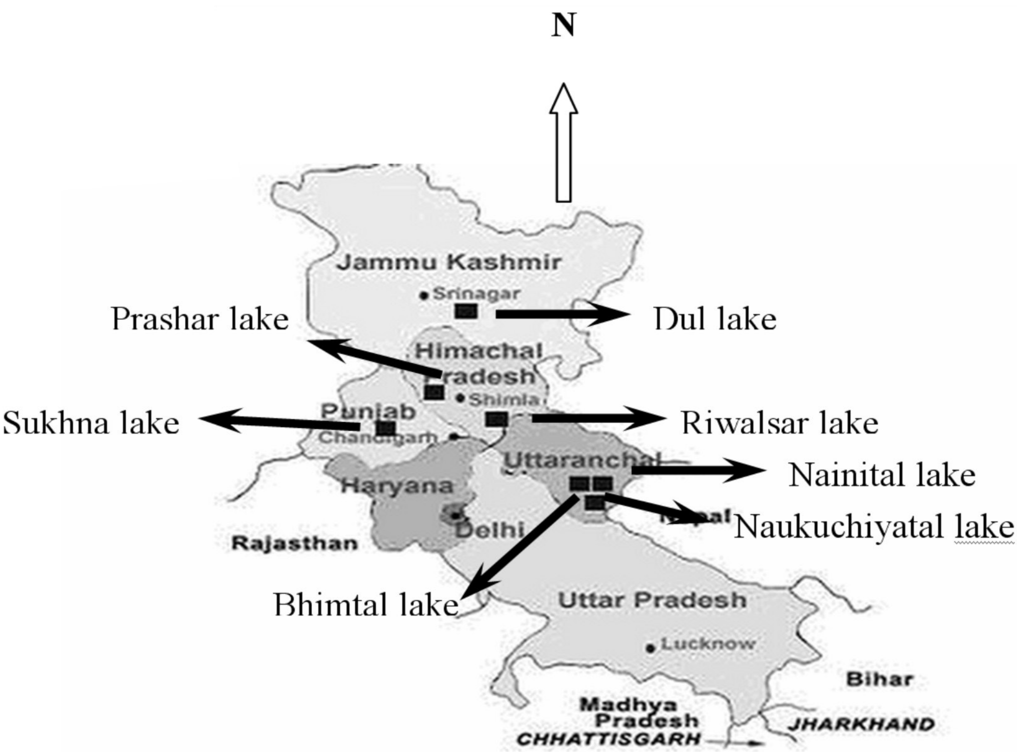


Figure 1. Map of study area of north Indian lakes

Bacterial analysis

The bacterial population (total viable count, TVC) in different samples was estimated by inoculating nutrient agar plates with 0.1 mL of suitable dilutions. The results were expressed as colony forming units (cfu)/mL, enumerated after 48 h of incubation. The water quality was determined by the standard most probable number (MPN) method. Coliforms were detected by inoculation of samples into tubes of MacConkey broth and incubation at (37 ± 1) °C for 48 h. The positive tubes were sub cultured into brilliant green bile broth (BGBB) and were incubated at (44.5 ± 1) °C. Gas production in BGBB at (44.5 ± 1) °C was used for the detection of faecal coliform after 48-h incubation. Faecal streptococci were detected by inoculation of water samples into Azide Dextrose broth and incubation at (37.5 ± 1) °C for 24–48 h (APHA, 1999). All the culture media were obtained from Hi-Media Pvt. Ltd., Mumbai, India.

Physiochemical analysis

Physicochemical parameters including total dissolved solids (TDS), conductivity and pH were analyzed on site at the time of sample collection by water analysis kit (Model LT-61, Labtronics, Guelph, Ontario, Canada) as per manufacturer instruction. Other parameters i.e. dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) were performed in laboratory by standard titrimetric method (Apha et al., 1999).

The data were analyzed statistically by using analysis of variance (ANOVA) to find out significance at 5 % levels. In figures, error bars indicate standard error of the mean, where error bars are not visible; they are smaller than the marker.

Results

The TVC values showed a regular trend (Figure 2). The values increased in summer season, thus generally highest counts were observed, intermediate in winter season and least in monsoon season, for each lake. The highest TVC was noted in the Dul lake water samples, where the values were as high as 189×10^6 cfu/mL in summer and the lowest values were recorded in case of Naukuchiyatal lake in monsoon season where values were 28×10^6 cfu/mL.

The total coliform count was high in all water samples (Figure 3), values ranged from 16/100 mL to 135/100 mL. The highest MPN (135/100 mL) was recorded during summer from Dul lake having peak tourist season. The least count MPN (16/100 mL) was obtained in monsoon from Naukuchiatal with less tourist or human activities. Even the water samples during less human activities in monsoon and winter seasons were found not suitable for drinking as per the Bureau of Indian Standards (BIS), (1991).

Figure 2. Total viable count (TVC) of different lake samples

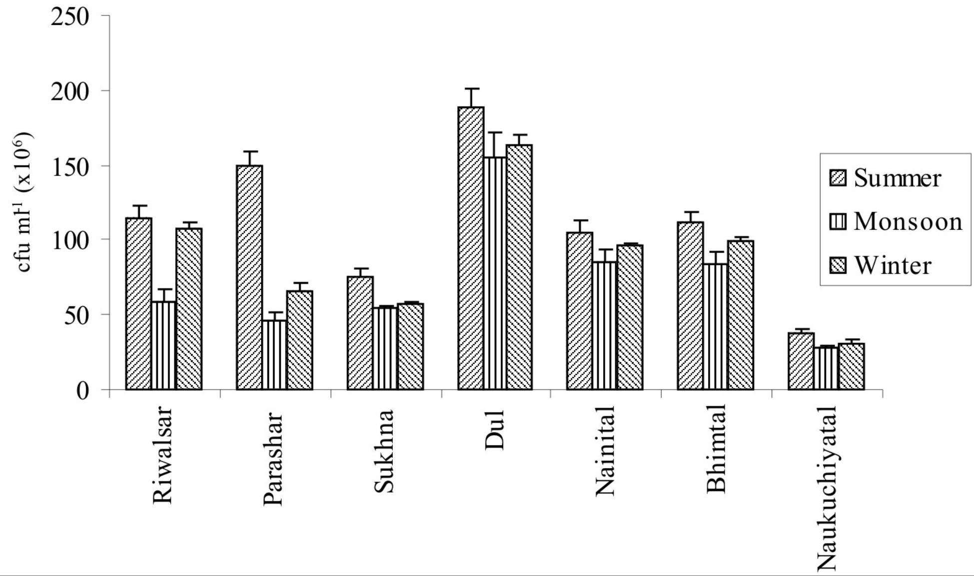


Figure 3. Total coliform (TC) count per100 ml of water sample

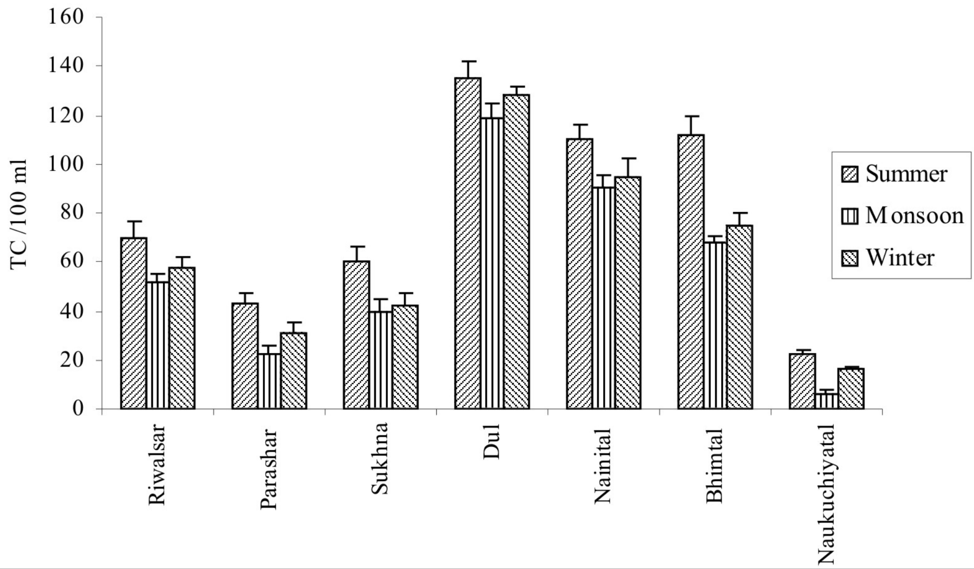


Figure 4. Faecal coliform (FC) count per 100 ml of water sample

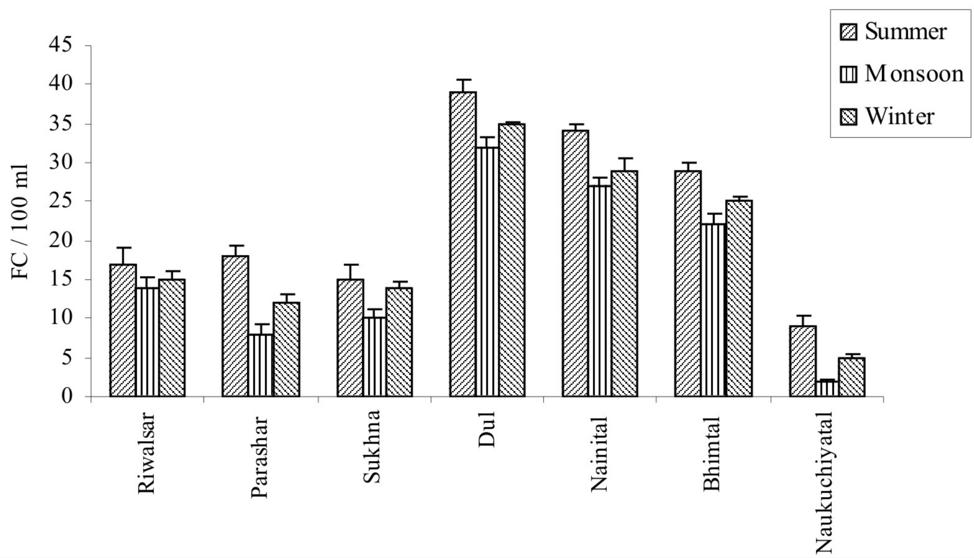
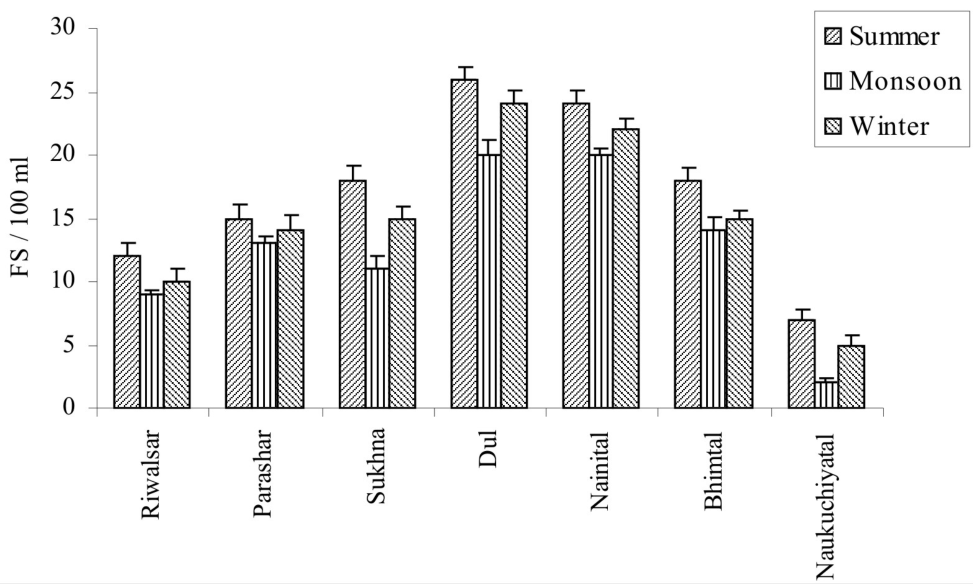


Figure 5. Faecal Streptococci (FS) count per 100 ml of water sample



Results for FC and FS counts have also shown a similar trend to TVC and TC, i.e. higher in summer season, intermediate in winter season and least during monsoon season. (Figures 4 & 5). Highest FC count was observed in Dul lake (39, 32, 35)/100 mL and the lowest count (9, 2, 5)/100 mL was observed in Naukuchiatal lake during summer, monsoon and winter seasons, respectively. Lake Nainital and Bhimtal have also shown higher number of FC after Dul lake. Similar trend was also observed in FS, the higher count (26, 20, 24)/100 mL in Dul Lake followed by Nainital (24, 20, 22)/100 mL during summer, monsoon and winter seasons, respectively, while the least count (7, 2, 5)/100 mL was observed in lake Naukuchiatal.

Conductivity and TDS in all the sites were found to be well with in the minimum prescribed limits (APHA et. al. 1999) (Table 2). The TDS value for water samples ranged from 24.1 mg/L to 198.9 mg/L. The TDS values; though within minimum permissible limits showed a regular trend of increasing value during winter, monsoon and summer samples (except for Riwalsar and Sukhna lakes). Conductivity of samples ranged from 0.035 S/cm to 0.46 S/cm. pH value showed a decreasing trend during summer season but for monsoon and winter it was nearly same, though the values were found to be neutral for most of the samples, but overall the pH increased with decrease in temperature i.e. in winter season.

Table 2. Physicochemical characteristics of lake water samples

Sampling area (Lakes)	**Seasons**								
	Summer			**Monson**			**Winter**		
	TDS	Conductivity	pH	TDS	Conductivity	pH	TDS	Conductivity	pH
Riwalsar	139.9	0.207	7.3	130.8	0.194	7.2	131.90	0.217	7.1
Prashar	27.7	0.041	6.3	24.9	0.037	5.9	24.10	0.035	7.1
Sukhna	133.1	0.198	6.7	126.3	0.187	7.1	126.70	0.189	7.4
Dul	147.7	0.222	6.6	132.7	0.197	7.8	99.00	0.147	7.8
Nainital	190.5	0.460	7.8	188.3	0.460	7.9	186.60	0.450	8.0
Bhimtal	198.9	0.200	7.6	178.6	0.180	7.7	164.20	0.160	7.9
Naukuchiatal	133.7	0.130	7.4	133.4	0.130	7.6	132.20	0.120	7.6

TDS mg/e at 200 mg/kg; Conductivity (2M) (S/cm)
Values are average of triplicate

Figure 6. Dissolved oxygen (mg/l) from lake water samples

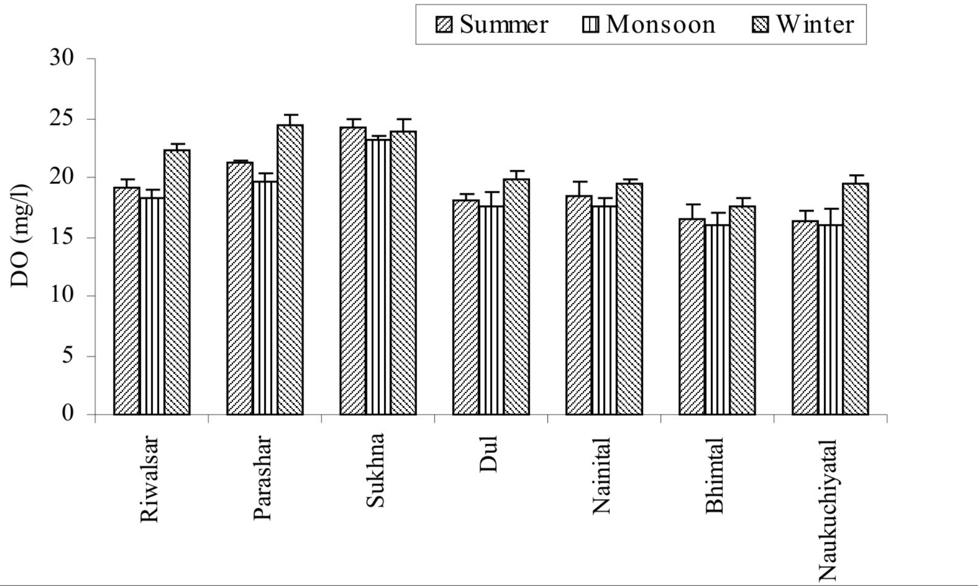


Figure 7. Biological oxygen demand (mg/l) from lake water samples.

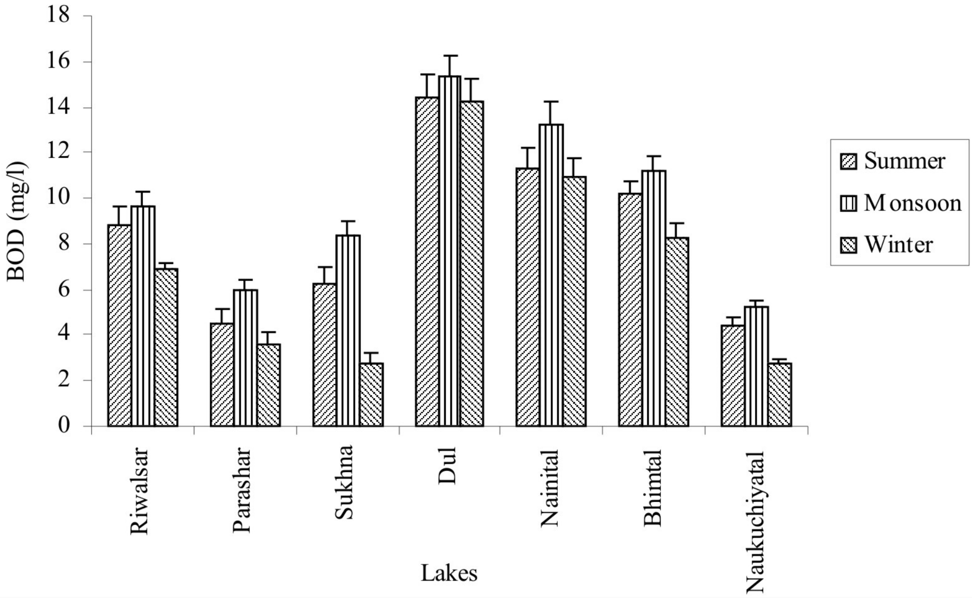
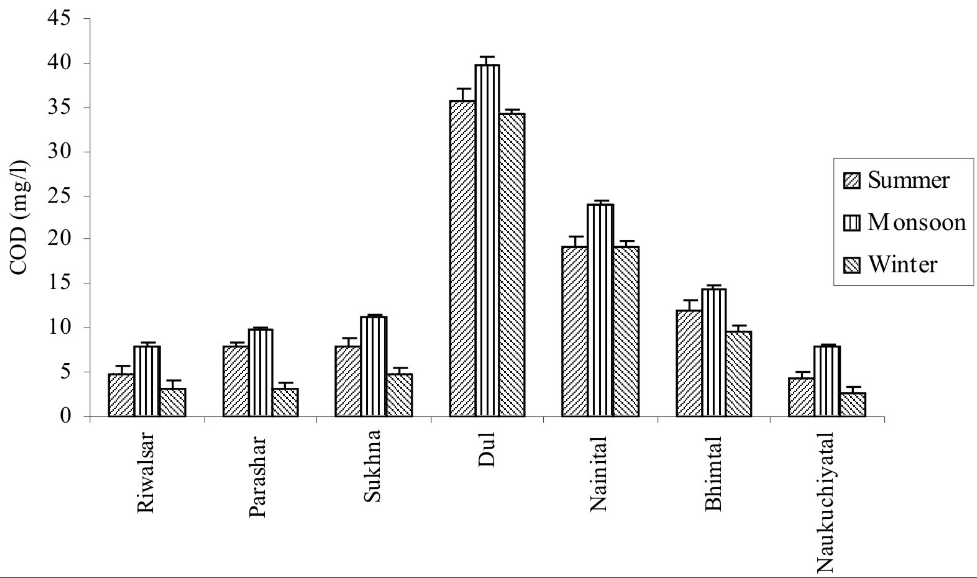


Figure 8. Chemical oxygen demand (mg/l) from lake water samples



The DO values ranged from 13.2–16.8 mg/L in summer samples, 16.4–24.2 mg/L in monsoon samples and 17.1–24.4 mg/L in winter samples (Figure 6). Lake Prashar showed a remarkable increase in DO in winter season. Though, in general the DO content of all the lakes show a uniform trend with varying seasons i.e. least during summer and highest during winter and intermediate in monsoon season. However, all the samples were found to be saturated with oxygen and were fit for bathing, wild life and irrigation with respect to the amount of dissolved oxygen.

The BOD value for most of the water samples were above the permissible limits (Figure 7), except that in Sukhana (winter), Naukuchiatal (winter) where BOD values were low, thus making water fit for drinking and other purposes. Samples in monsoon season have high BOD values and thus, the water was not fit for drinking. Considerably higher COD values were recorded in the monsoon season in all sites of study area, the COD ranged from 3.2 mg/L to 42.5 mg/L in all samples (Figure 8).

Discussion

In the present study, all the TVC values were found to be high in all the water samples from all the lakes. The bacterial load increased with increasing human activities during summer season, thereby indicating the direct effect of human activities on the bacterial population. Relatively very high values of TVC were observed in Dul Lake (Jammu & Kashmir), which may be accounted by the fact that here Shikaras (house boats) on the lake are very common and find a special attraction amongst large number of tourists from India and the world. The results of the present study draw support from the findings of Sood et al., (2008), (Radha & Seenayya, 2004) who have worked on the bacteriological water quality of Gangetic river system and Husainsagar lake respectively and have reported that the places with greater population influx experience a comparatively higher bacterial load.

The TC count in Dul lake in summer season was also highest; which indicates that the lake water is being contaminated form direct human activities (i.e. bathing, excreting in the house boats, small boats being used to sale eatables). During monsoon and winter period, fewer tourists visit the place, therefore less human activities results in fewer microbial counts. Surface waters may become a carrier of disease producing bacteria when it comes in contact with human and animal infective materials. These lakes are being visited by a lot of foreign and Indian tourists every year. Niewolak (2000) has also attributed the repeated increase of TVC and TC to the increase of the amount of pollution from drainage catchment in a study carried out on river water quality of Wigry national park, Poland.

As per the general observations, highest faecal coliform and faecal streptococci counts were found in summer season samples of Lake Dul, Nainital followed by Bhimtal, which is again indicative of the fact that the water sample is being contaminated from direct human activities. Lake Nainital and Bhimtal being on hill station is favorable tourist spot during summer season. Low count of FC and FS were observed in lake Naukuchiatal, this might be because of the fact that this lake is at high altitude and have low temperatures, so optimum temperature conditions are not available for the survival of these thermotolerant organisms. Geldreich (1970) has reported out that FC: FS higher than 4.0 points to pollution originating from people, but in present study the values were found to be below 2 thereby suggesting an alternative source of pollution i.e. from grazing animals.

With respect to the physicochemical parameters, in all the lake water samples the DO was found to increase with decrease in human activities during monsoon and winter seasons, during which the DO was highest. The human activities include visits of tourists, washing, bathing, grazing of animals near the lake or in catchments area etc. In all the lake samples the BOD varied from 3.6 to 15.3 mg/mL. During monsoon the highest BOD and COD was observed in lake Dul followed by Nainital and Bhimtal and during winter BOD decreased, lowest BOD and COD was observed in lake Naukuchiatal. Earlier, Sood et al., (2008) have studied water quality of Ganga in Uttarakhand Himalayas, India and have reported a high level of BOD due to introduction of organic matter into the system as a result of anthropogenic activities. Also these values showed a proportional relation with human activities i.e. the fewer the human activities (in winter), the better the water with respect to physicochemical parameters. Higher BOD values in most of the water samples suggest that either these lakes are rich in organic matter or organic matter is being introduced in the lakes by anthropogenic activities (Tijani et al. 2005), since, BOD provides a direct measurement of state of pollution. Relationship between BOD, COD and microbial count was found inversely proportional, implying that at high organic loading rates, the ecosystem retards the growth of aerobic microorganisms and favors the growth of anaerobes; our findings draws support from Mtui & Nakamurs (2006).

The use of coliform bacteria as a measure of the faecal contamination of lakes and streams has been in practice for many years. Our study gives an indication of the extent of relation of microbial pollution and physiochemical parameters; any further addition of wastes may deteriorate the existing hygienic quality in the area. These results suggest that increase of population of coliforms in a lake environment are directly proportional to the degree of sewage and human waste pollution, which is refected by BOD and COD levels. Sah et al. (2000) have stressed on the point that the pollution in rivers and water bodies from industries may adversely affect aquatic life of water bodies’ as well human health in the vicinity of rivers/lakes.

Lake Naukuchiatal was found to be safe with respect to bacteriological as well as physicochemical parameters. This can be accounted by the fact that out of all the other lakes, Lake Naukuchiatal is least visited by the tourists and is not a very famous recreation spot, but urbanization, visits of local inhabitants and grazing animals in nearby area resulted in introduction of some amount of organic matter. Tijani et al. (2005) have stated that in many developing countries, increasing agricultural activities, urbanization and industrialization leads to ever increasing contamination of streams/rivers and lakes/reservoirs, which are usually the main sources of drinking water. This clearly highlights the fact that natural stagnant water resources; though find special attraction for tourism and recreation activities, this practice degrades the quality of water.

In this study, we have collected water samples from lakes of different size and depths, but in order to represent the results in a simplified way, the results of various samples of a particular lake have been presented in a composite manner. In a broad view, the lakes with higher catchments area, soil cover and land use are more polluted, owing to more anthropogenic activities. McLellan et al. (2001) stated that faecal pollution indicator organisms can be used to a number of conditions related to the health of aquatic ecosystems and to the potential for health effects among individuals using aquatic environments. The presence of such indicator organisms may provide indication of water-borne problems and is a direct threat to human and animal health. Our studies on microbial ecology and physiochemical analysis in the north Indian lakes in relation to pollution have clearly revealed that there is significant presence of bacterial indicators of faecal pollution the situation is serious and alarming. Presence of bacterial indicators of faecal contamination in lakes clearly revealed the bacteriological status of the water at that site. For this reason, monitoring of microbial contamination in lakes should be an essential component of the protection strategy in that area area. The base line data generated on bacteriological water quality of lakes may serve as biomonitoring standard and comparisons for other lakes and may be useful for all scientists, decision makers and resource managers working with environmental planning and management of such areas.

Conclusions

The rationale of this study was to evaluate the impact of season and human activities on the pollution status of seven important north Indian Lakes. This study revealed that north Indian lakes are threatened by high influx of pollutants and enteric pathogenic contamination and it can be concluded that Dul Lake is most polluted and the Lake Naukuchiatal is the least. The constant surveillance of these water bodies with respect to the bacterial indicators and physicochemical parameters provides us with the opportunity of true microbiological monitoring of the area as well as proper management actions could be applied in order to improve the quality of these lakes and consequently reduce public health risk.

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