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Spatial and Temporal Fluctuations in the Physico-Chemical Limnology of Mangla Dam (Pakistan)

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Abstract.- Mangla dam consists of five distinct basins receiving water from two perennial and two non-perennial rivers. Studies were carried out to find spatial and temporal variation in physicochemical characteristics of the surface water in five basins of the dam from January 2009 to December 2010. The result showed that the mean values of temperature, Secchi Depth, pH, Dissolved Oxygen and Conductivity were 22.8^{o}C, 14.5 cm,7.81, 7.9 mg/L and 441.7 μS/cm. The mean values for total alkalinity, total hardness and total dissolved solids remained 120.0 mg/L, 195.9 mg/L, and 314.0 mg/L respectively. Mean values for nitrates (2.44 mg/L) resulted in higher phytoplankton count (92/ml) in the dam. In general, the water quality followed a cyclical pattern with summers favoring higher primary productivity. Except for pH and dissolved oxygen, almost all the water quality parameters varied significantly (P<0.0001) among seasons and basins with no interaction amongst them. Spatially, there was more resemblance between Mangla and Khad basins, and Poonch and Jhelum basins Temporally hot season and monsoon show more similar water quality separating them from cold season and post monsoon.

Key words: Mangla dam, basins, Jhelum, Poonch, spatial, temporal, Physico-chemical limnology.

INTRODUCTION

The obstruction of natural flow of rivers to form reservoirs brings about changes in ecological process often resulting from changed physico-chemical conditions. Several factors determine the water quality of these reservoir which includes seasonal precipitation, wind action, geologic origin of the catchment basin and pattern of hydrological cycle prevalent in the dam (Tundisi and Straskraba, 1999), the transportation of nutrients by tributary rivers (Tufford and McKellar, 1999; Friedl and Wüest, 2002), seasonal climatic changes (Chapman, 1996; Barik *et al.*, 2010), deforestation, and land use in catchment area (Dar and Romshoo, 2008). In large reservoirs, these changes in water quality and limnological characteristics create distinct habitats often forming three distinguishing zones which are riverine zone characterized by the fluvial environment, lacustrine zone nearest to the dam, and a middle transition zone (Tundisi, 1996; Moretto and Nogueira, 2003; Serafim *et al.*, 2006; Sthapit *et al.*, 2008). This change from riverine to lacutarine environemtns have a bearing on the distribution and abundence of distinct biota inhibiting each zone (Benedito-Cecilio and Agostinho, 2000; Friedl and Wüest, 2002; Sthapit *et al.*, 2008).

Many physico-chemical parameters have successfully been used to predict the fish production potential of the reservoirs (Moyo, 1994; Amarasinghe *et al.*, 2002; Sugunan *et al.*, 2002; Janjua *et al.*, 2008) and have proved to be invaluable tools in the sustainable management of water bodies especially in the regions like Pakistan where the flow of rivers fluctuate widely due to varied nature of snow melt and rainfall in the catchment areas.

Mangla dam is a multipurpose dam primarily providing storage for two perennial rivers, Jhelum and Poonch, and two non-perennial rivers namely Kanshi and Khad (Sheikh, 2007) forming distinct habitats. Limited information is available on the spatial and temporal variation in the physico-chemical limnology of the reservoir. Rafique *et al.* (2002) have studied the seasonal changes in the limnology of Mangla reservoir near Sukhian dike in the Mangla basin. The study did not provide any information on water quality of other basins of the dam. The present study, therefore, focused on the spatial and temporal changes in the limnology of all

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five basins of the dam.

MATERIALS AND METHODS

Study site

Mangla dam is an earth-filled structure founded on soft rocks of Plio-Pleistocene series designated as Siwaliks. The bedrocks contain clays and intercalated sandstones with rocks belonging to integradations *i.e.* siltstone/ sandy siltstone/ clayey silt (Altaf-Ur-Rehman, 1986). The dam situated at the junction of four rivers has narrow flanks extending into the river valleys forming five distinct basins known as Mangla, Khad, Poonch, Jhelum and Jari pockets/basins of the dam (Fig. 1). The main storage is in Khad and Poonch rivers and extends to Jhelum-Kanshi and Jari Nullah. The physical features of the dam are highlighted in Table I.

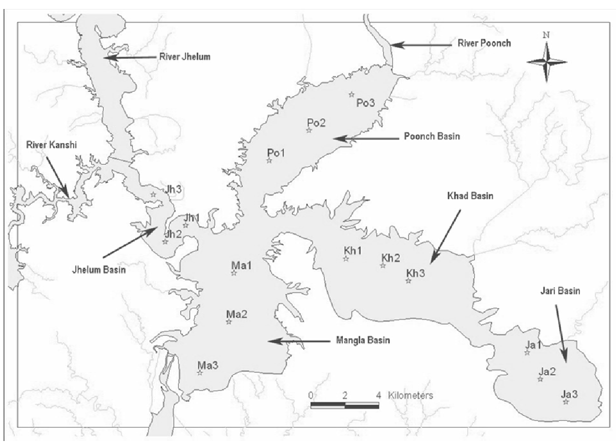

Fig. 1. Five basins of Mangla Dam showing location of sampling stations

Seasons

For the purpose of this study, the two broad seasons of summer and winter are divided into four sub-seasons primarily following Khan *et al.* (2010). These seasonal classification used in this study is given below:

Cold season starting from mid-November to mid-April with mean monthly temperature below 29°C and rainfall less than 6 cm

Hot season (Summer) from mid-April to June with mean monthly temperature above 30°C and rainfall below 3 cm

Monsoon season ranging from July to mid-September having mean monthly temperatures below 30°C and rainfall greater than 6 cm.

Table I: Summary of physical characteristics of Mangla Dam.

Parameter	Before raising	After raising
Dam		
Max height above core trench (m)	138.4	378.7
Max height above river bed (m)	115.5	-
Crest elevation SPD (m)	376.1	-
Length of crest (m)	3,353	3,400
Spillways total discharge capacity (M^3S^{-1})	6,000	6,000
Reservoir		
Normal max conservation level (SPD) (m)	366.4	378.7
Min operational level (SPD) (m)	317.0	317.0
Original gross storage (MCM)	7252.9	-
Original live storage (MCM)	6,586.8	-
Existing gross storage (MCM) (as per 2005)	5,921	9,132
Existing Live storage (MCM)	8,185	8,930
Surface area (Km^2)	265.0	329.8
Maximum depth (m)	90	99
Mean depth (m)	22.5	27.7
Depth ratio	0.25	0.28

MCM= Million cubic meter,
SPD = Survey of Pakistan Datum

Post Monsoon (Warm Season) lasting from mid-September to mid-November having average monthly temperatures below 25°C with rainfall less than 3 cm

Physico-chemical parameters of dam water

Keeping in view the morphomteric features of the dam, three fixed sampling stations were identified in each of the five basins of the Mangla dam (Fig. 1). Water samples were collected at all the sampling stations on monthly basis from Jan 2010 to Dec 2010. The physicochemical parameters like water temperature, Dissolved Oxygen, pH, electrical conductivity were measured *in situ* during the field trips using Hanna Portable Combo waterproof pH/EC/TDS/Temperature Tester. Secchi depth was noted using a standard 20 cm diameter Secchi disk. Triplicate water samples from just below the surface were collected for analysis in 1L containers and brought in laboratory for analysis of calcium, Magnesium, Chlorides, total alkalinity, total hardness, TDS, and Nitrates using standard methods (APHA, 2005) and Hach (2003) procedures. *Ex situ* biological analysis of fixed samples was conducted following Vollenweider (1969) for the determination of Chlorophyll-*a* and phytoplankton count. Repeated measures analysis of variance (ANOVA) was used to find the effect of seasons and basins. When the main effect of seasons or basins was detected then the mean parameters values for seasons or basins were subjected to Tukey's HSD test to find the similarities/ differences among seasons or basins. Multivariate cluster analysis was used to develop dandrograms based on average linkage and correlation coefficient distance of different water quality parameters for basins and seasons. All statistical analysis was performed using R Statistical Package (R Development Core Team, 2010).

RESULTS

Physical variables

A summary of the descriptive statistics of different water quality parameters recorded along with spatial and temporal changes are shown in Table I. The overall mean surface water temperature recorded from January 2010 to December 2010 was 22.8°C which varied widely with minimum and maximum recorded temperatures of 7.3°C and 37.0°C. In general, higher temperatures were recorded from the Jari Basin of the dam with minimum temperatures recorded in the Jhelum Basin. Temporally the minimum temperatures recorded were in months of January and February, which started rising and reaching higher value during the months of June to August. During the present study, temperature in the Mangla and Khad basins dropped to as low as 6°C on 22nd Jan 2010. Similarly mean value for water transparency in the dam as measured by Secchi disk remained 25.59±3.69 cm with wide spatial and temporal variations (Table II). It was observed that during the months of filling of dam (from March to July), the lower Secchi depth readings were caused by the incoming silt especially in the Poonch, Jhelum and Mangla basins of the dam with lowest values in Poonch basin. Lower Secchi depth readings due to planktons were more often observed in Jari basin which also showed slightly higher temperatures when compared with other basins of the dam.

Mean value for the Dissolved Oxygen was 7.95±1.26 mg/L and for pH it was 7.81±0.59. These values were generally higher in the Jari Basin of the dam when compared with the remaining basins. Khad basin recorded higher values of pH closely followed by Khad and Mangla basins (Table II). Average values did not vary much during the four season and these remained 7.67, 7.96, 7.84 and 7.83 for winter, summer, monsoon, and post monsoon respectively. On 22nd Jan 2010, the dissolved oxygen dropped to 3.60 mg/L in Mangla and Khad basins. These low concentrations might have resulted from winter overturn as the temperature during period also was lowest recorded during this study. These low concentrations combined with cold shock might have been the reason for high fish mortalities in these two basins during this period. Conductivity of water in Mangla dam also varied widely ranging from 386.20 to 506.49 μS/cm with an average value of 441.77±26.67 μS/cm. Jari basins recorded higher EC values followed by Khad, Mangla, Poonch and Jhelum basins which are 457.78, 458.84, 446.12, 431.99 and 414.12 μS/cm respectively (Table II). Lower value of EC were recorded during the month of winter as compared to Monsoon which indicates the addition of ions from the catchment area.

Chemical variables

Mean values for major ions of magnesium, calcium and chlorides varied widely with basin as well as with season (Table II). For example, Chloride in Mangla dam water varied from 5.71 to 18.86 mg/L with an average value of 11.79±2.85 mg/L. The mean values for calcium and magnesium were 28.88±3.34 mg/L and 16.98±4.86 mg/L respectively. Most ions did not follow a definite pattern and varied significantly during different seasons.

Total alkalinity of the water is a combination of the carbonate and bicarbonate alkalinity. Results obtained during the study showed that the values of bicarbonate alkalinity were higher compared with the carbonate alkalinity. Mean values for carbonate, bicarbonate and total alkalinity of the dam water remained 47.59±14.27, 148.41±19.98 and 120.03±10.67 mg/L respectively. Temporally, higher alkalinity values were recorded during the summer and monsoon which gradually decreased during the monsoon (Table II). Jari basin recorded higher values of total alkalinity (Table III). In general, values of total alkalinity varied more widely in Mangla and Poonch basins. When basins of the dam are compared, Jari Basin recorded higher levels of alkalinity followed by Khad, Mangla, Poonch and Jhelum basins of the dam in descending order. The mean value for total hardness as $CaCO_3$ recorded was 195.99±30.59 mg/L with Jari basin recording higher levels of harness followed by Khad, Mangla, Poonch and Jhelum basins in the descending order. Hardness followed a definite pattern and tended to increase with the onset of summer when the dam starts receiving water due to melting of ice in the catchment area. It reached at the highest values during the monsoon and then begin to decrease reaching minimum values during the colder months. On the other hand TDS did not follow a definite pattern in the dam water and varied greatly during different seasons and basins. Jari and Khad basins recorded relatively higher levels of TDS. Its value varied seasonally and the averages remained 305.66, 313.30, 325.54 and 314.67 mg/L for winter, summer, monsoon and post monsoon respectively (Table II).

The mean value for the Nitrates recorded was 2.44±0.99 mg/L. These values were generally higher in the Jari Basin of the dam when compared with the remaining basins of the dam. Higher values of nitrates were recorded during the summer as compared with the lowest values recorded during winter (Table II) which is probably due to the addition of nutrients received from the catchment area.

Biological variables

Chlorophyll-*a* concentration which is a good indicator of nutrient condition (Brylinsky and Mann, 1973) had mean values of 25.58±11.51 µg/L with wide a variation between seasons and basins (Table II). This closely followed with high fluctuations in phytoplankton counts in seasons and basins, and the mean count remained 92±43.82 cells per milliliters.

Table II.- Temporal and spatial variation in mean values of water quality parameters recorded in the Mangla Dam from Jan 2010 to Dec 2010.

Water quality parameter	Whole reservoir descriptive statistics				Whole reservoir temporal averages				Spatial (Basins) averages				
	Minimum	Maximum	Mean	CV	Winter	Summer	Monsoon	Post Monsoon	Mangla	Khad	Poonch	Jhelum	Jari
Temperature (°C)	7.30	37.00	22.83	0.40	13.32^{a}	27.80^{b}	31.83^{c}	20.92^{d}	24.75^{c}	25.83^{c}	25.20^{b}	16.51^{a}	28.78^{c}
Secchi Depth (cm)	18.10	33.30	25.59	0.14	23.26^{a}	28.52^{b}	25.23^{b}	26.38^{b}	24.15^{a}	24.65^{ab}	28.85^{c}	$24.47a^{b}$	26.46^{bc}
Dissolved Oxygen (mg/L)	6.30	10.40	7.95	0.10	7.70^{a}	8.18^{b}	8.01^{ab}	8.03^{ab}	7.94^{abc}	8.01^{bc}	$7.89a^{b}$	7.18^{a}	8.74^{c}
pH	7.80	9.50	7.81	0.08	7.67^{a}	7.96^{a}	7.84^{a}	7.83^{a}	8.06^{a}	8.08^{a}	7.41^{a}	7.60^{a}	8.89^{a}
Conductivity (μS/cm)	386.20	506.49	441.77	0.06	422.99^{a}	446.11^{b}	459.51^{c}	446.18^{bc}	446.12^{c}	458.84^{c}	431.99^{b}	414.12^{a}	457.78^{c}
Calcium (mg/L)	21.98	35.82	28.88	0.12	28.38^{a}	29.48^{a}	27.86^{a}	30.46^{a}	30.17^{ba}	30.11^{ba}	26.88^{b}	26.77^{b}	30.45^{a}
Magnesium (mg/L)	10.03	31.63	16.98	0.29	13.42^{bc}	17.34^{b}	22.22^{c}	15.75^{a}	17.35^{a}	16.85^{a}	17.19^{a}	17.32^{a}	16.24^{a}
Chlorides (mg/L)	5.71	18.86	11.79	0.24	11.03^{a}	13.57^{b}	10.30^{a}	12.89^{b}	11.46^{ab}	12.20^{ab}	13.02^{b}	10.62^{a}	11.67^{ab}
Total Hardness (mg/L)	137.93	273.32	195.99	0.16	179.18^{a}	208.19^{b}	211.44^{b}	188.15^{a}	194.22^{b}	216.15^{c}	180.55^{b}	164.33^{a}	224.71^{c}
Total Alkalinity (mg/L)	98.33	146.24	120.03	0.09	111.99^{a}	125.90^{b}	127.99^{b}	115.36^{a}	120.92^{bc}	124.65^{c}	$116.71a^{b}$	112.39^{a}	125.47^{c}
TDS (mg/L)	266.67	348.68	314.04	0.07	305.66^{a}	313.30^{b}	325.54^{c}	314.67^{b}	315.12^{c}	335.19^{d}	302.62^{b}	282.33^{a}	334.95^{d}
Nitrates (mg/L)	0.72	3.89	2.44	0.41	1.86^{a}	3.02^{b}	2.89^{b}	2.05^{a}	2.95^{b}	3.04^{b}	1.69^{a}	1.42^{a}	3.09^{b}
Chlorophyll-a (µg/L)	3.61	44.12	25.58	0.45	18.77^{a}	33.02^{b}	31.00^{b}	19.86^{a}	29.89^{b}	32.51^{b}	17.06^{a}	14.02^{a}	34.38^{b}
Phytoplankton Count (No./ mL)	14	172	92	0.48	65^{a}	119^{b}	115^{b}	69^{a}	104^{b}	119^{bc}	58^{a}	50^{a}	126^{c}

Note : In each group (Temporal and Spatial), average values bearing different letters in superscript were statistically different based on post hoc comparisons using the Tukey's HSD test.

Table III.- Summary of Analysis of Variance (ANOVA) of the effect of season, basin and their interaction on different water quality parameters in the Mangla Dam. (mean square (MS) values and significance levels for the F-test are shown)

Water quality parameter (Dependent Variable)	Source of Variation					
	Season		Basin		Season x Basin	
	MS	P-Value	MS	P-Value	MS	P-Value
Temperature (°C)	2,196.33	<0.001	368.84	<0.001	14.01	ns
Secchi Depth (cm)	131.96	<0.001	82.29	<0.001	7.01	ns
Dissolved Oxygen (mg/L)	3.51	<0.05	10.16	<0.001	1.84	ns
pH	0.13	ns	1.83	ns	0.56	ns
Conductivity (μS/cm)	7,804.80	<0.001	9,433.40	<0.001	175.30	ns
Chlorides (mg/L)	62.45	<0.001	17.23	<0.05	6.95	ns
Total Hardness (mg/L)	7,695.20	<0.001	14,886.20	<0.001	19.10	ns
Total Alkalinity (mg/L)	1,885.05	<0.001	772.50	<0.001	17.09	ns
TDS (mg/L)	2,146.80	<0.001	12,457.20	<0.001	48.00	ns
Nitrates (mg/L)	12.07	<0.001	14.48	<0.001	0.36	ns
Chlorophyll-a (µg/L)	1,633.76	<0.001	2,029.70	<0.001	22.63	ns
Phytoplankton Count (No./ mL)	22,856.60	<0.001	26,230.90	<0.001	120.20	Ns

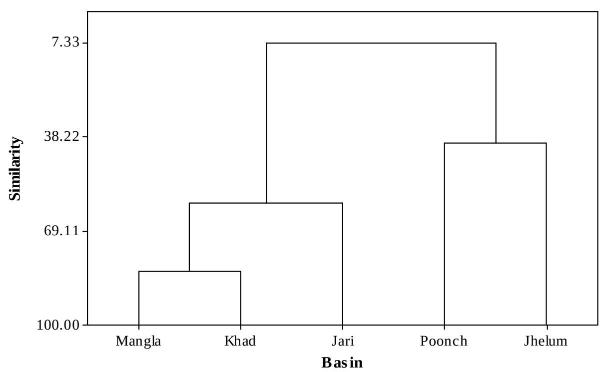

Fig. 2: Dandrogram developed on average linkage and correlation coefficient distance of different water quality parameters in five basins of the Mangla Dam

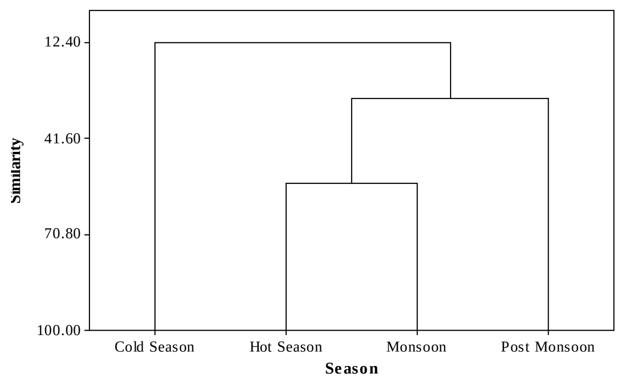

Fig. 3: Dandrogram developed on average linkage and correlation coefficient distance of different water quality parameters in the Mangla Dam during four seasons

Lowest values for Chlorophyll-*a* and phytoplankton count were recorded in winter while the highest values for both parameters were recorded in summer. This may be due to the addition of increased amount of nutrients coming into the dam from the catchment area. Further, the two parameters were highly correlated (r = 0.95). Spatially the phytoplankton counts and chlorophyll-*a* concentrations were higher in the Jari basin followed by Khad, Mangla, Poonch, and Jhelum basins of the dam.

When the data of physico-chemical parameters was subjected to repeated measures analysis of variance (ANOVA) to find the main effect of seasons, basins, and their interaction if any, the results showed (Table III) that all parameters except Dissolved Oxygen and pH varied highly significantly (p<0.001) during different seasons. In case of Dissolved Oxygen, there was significant (p<0.05) different among seasons while the pH did not vary significantly (p>0.05) during different seasons. The main effect of basins also had highly significant (p<0.001) effect on all parameters except Chlorides which varied significantly with basins. The basins also did not have significant (p>0.05) main effect on pH. In case of all parameters, the

ANOVA did not find any interaction (p>0.05) among basins and seasons. The results of cluster analyses and resulting dandrogram is shown in Table II and Figure 2. The dandrogram show that Mangla and Khad basins are more similar and formed a pair. On the other hand, Poonch and Jhelum basins also formed a separate pair based on similarities while the Jari was more close to Khad/Mangla than Poonch/Jhelum. Similarly Figure 3 shows the dandrogram developed for four seasons which shows that the hot season and monsoon were more similar than the other two seasons. Their pair was closer to post monsoon than cold season.

DISCUSSION

The results of water quality parameters obtained during this study are comparable to those in other water bodies in the region (Mirza and Khuhawar, 2006; Sarwar *et al.*, 2007; Khuhawar *et al.*, 2009). For example, Rafique *et al.* (2002) have reported the total hardness as high as 247 mg/L and total alkalinity as high as 310 mg/L in main Mangla basin of Mangla reservoir near Sukhian dike. Sarwar *et al.* (2007) also reported the total hardness as high as 180 mg/L in River Jhelum at Muzaffarabad in Azad Kashmir. Similarly, Khuhawar *et al.* (2009) reported comparable values of total hardness (200 mg/L), TDS (319.4 mg/L) and EC (499 μS/cm) in Baghsar Lake near Mangla dam. Present study shows that temperature values ranged from 7.10 to 38.40°C while Rafique *et al.* (2002) had reported these values to vary from 16-41°C. The marked difference in lower water temperature is due to the fact that they had investigated temperature of the Mangla dam in a small region of the main Mangla basin. During the study it was found that the temperature regimes in the dam followed closely with the hydrological cycle of the dam as the water in the dam is usually at its minimum during the early months of the year. Subsequently with the rise in the environmental temperatures, the snowmelt in the catchment basin leads to increased flows into the dam during March and April. In the summer, these inflows are augmented by the much higher inflows resulting from monsoon rainfall in the catchment area, thus filling the dam to its maximum level of the year. This filling up of the dam brings more uniformity in the water quality parameters in different basins. Using historical flow data from three sub basins of Indus catchment basin, Archer (2003) has shown distinct hydrological regimes prevailing in the basin with summer volume governed by melt of glaciers, and winter and monsoon flows mainly due to rainfall. These seasonal changes in the flow regime are probably the major reason of changes in seasonal water temperatures in different basins of the reservoir. In addition to this, the Secchi depth also varied significantly among seasons and basins. Light transparency and nutrient status are known to regulate the primary productivity of water bodies (Tilahun and Ahlgren, 2010). Britto and Carvalho (2006) have reported that the damming of large rivers creates artificial lakes that trigger a series of impacts which affect the physical, chemical and biological components in the ecological dynamics of the aquatic ecosystem formed by the impoundment. The high variability in water quality parameters note in the present study may be due to the impact of extrinsic factors (*e.g.* rainfall and surface run-of) and sub intrinsic factors (*e.g.* sedimentary or depositional nature) which prevailed during the rainy and dry seasons respectively. It is known that significantly change in water quality parameters directly influence the community structure of the macro-invertebrates (Callisto *et al.*, 2005), changes in the water temperature along with the seasonal variation in transparency and nutrient influx may be the reason of changes in the primary productivity of the dam observed during these studies.

The present study also found that the values for Nitrates, phytoplankton count and Chlorophyll-*a* also vary widely with seasons and basins (Tables III). Khad and Jari basin had higher values for nitrates (3.0 mg/L) which were correlated with the higher values of phytoplankton (126 and 119 respectively) and Chlorophyll-*a* (34.38 and 32.51 μg/L respectively). These higher values of nitrates are comparable with those (2.9 mg/L) observed by Khuhawar *et al.* (2009) in Baghsar Lake near Mangla dam. Primary productivity is the primary source of energy in the aquatic water bodies and is directly related with the water temperatures (Verma and Mohanty, 1994), available nutrients in soil and water (Moss *et al.*, 1980). High phytoplankton pulses in monsoon and spring are typically associated with higher nutrient levels during these months (Bandyopadhyay, 2002). The changes in flow rates from the feeder rivers bring about fluctuations in nutrients resulting in the growth of certain species at different nutrient levels thus forming distinct spatial and temporal patterns of dominance and abundance (Nogueira, 2000; Paul *et al.*, 2007).The growth of certain species is favored in response to increased flow rates and addition of increased fresh inputs from the main feeder rivers. The interaction between physical and biological process in a reservoir occurs over a range of spatial and temporal scales. This inherent coupling of biotic and abiotic process is often discussed in the context of "multiple driving forces hypothesis". It has been proved that at large scale, the spatial heterogeneity of zooplankton communities primarily undergo environmental control through abiotic factors (Pinel-Alloul, 1995). On the other hand in shallow reservoirs, the physical factors especially wind plays an important role in shaping the environmental variables like turbidity, and suspended solids thus forming seasonal spatial gradients by the physico-chemical, and biological descriptors (Cardoso and Marques, 2009). The differences in water quality and associated spatial/ temporal heterogeneity in the limnological characteristics brings about differentiation of the five basins riverine and lacustrine habitats.

CONCLUSIONS

The findings of this study showed that there is wide variation in spatial and temporal physicochemical chemistry of the Mangla reservoir. Furthermore, the Jari and Khad basins have water quality that supports more primary productivity than in other basins of the reservoir.

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