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Physico-chemical Parameters of Koshi River at Kushaha Area of Koshi Tappu Wildlife Reserve

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Abstract
The Koshi river is the major tributaries of the Ganges which originates from the snowy peaks of Tibetan plateau in the central Himalayas. Its total catchment area is 60,400 km^2, of which 28,140 km^2 lies in Nepal, while the remainder is situated in Tibet. It passes from Nepal to India via the Koshi Tappu Wildlife Reserve area of Nepal. It destroys large area through floods, especially in India. This paper deals with the air temperature and phyco-chemical parameters like temperature, transparency, pH, oxygen, carbondioxide, alkalinity, hardness, chloride and biological oxygen demand of water of Koshi river at Kushaha area of Koshi Tappu Wildlife Reserve. The water temperature was recorded maximum in summer season but the transparency, pH, dissolved oxygen, total alkalinity and total hardness were recorded maximum in winter season. Similarly, free carbondioxide was maximum in rainy season and chloride and biological oxygen demand were recorded maximum in summer season. The air temperature and water temperature had positive and significant correlation with free carbondioxide and biological oxygen demand. Dissolved oxygen had positive and significant correlation with pH, total alkalinity and total hardness. Similarly, total alkalinity had positive and significant correlation with transparency, total hardness, chloride etc.

***Key words*:** Koshi River, physico-chemical parameters.

Introduction

Though vast numbers of limnological investigations have been carried out in other countries, only a few works have been done in Nepal. Loffler (1969) reported the dominance of calcium among cations, low chloride and less than 1μg/l phosphorus from the high altitude lakes of Mount Everest region. Lohman *et al*. (1988) studied pre and post monsoon limnological characteristics of lakes of Pokhara and Kathmandu valleys. They recorded low alkalinity and conductivity in the lakes of Pokhara valley. McEachern (1994) reported 8.4 pH, 0.03 mg/l phosphate and 8.5 mg/l dissolved oxygen in Narayani, a lowland (<1000 m) river of Nepal. Aryal and Lacoul (1996) studied water quality and diversity of diatoms in Punyamati river. They reported high pH, total hardness, BOD at polluted site, where transparency and dissolved oxygen were low. Ormerod *et al*. (1996) reported the pH range 7.3 to 8, chloride 0.4 mg/l to 1.4 mg/l, nitrate 0.06 mg/l to 0.28 mg/l, and phosphate 0.02 mg/l to 0.04 mg/l from the highland (>2000 m) rivers of Nepal.

The study site, Kushaha area of Koshi river is inside the Koshi Tappu Wildlife Reserve and lies between 26°37'14.4"N latitude and 87°01'26.1"E longitude (Fig. 1).

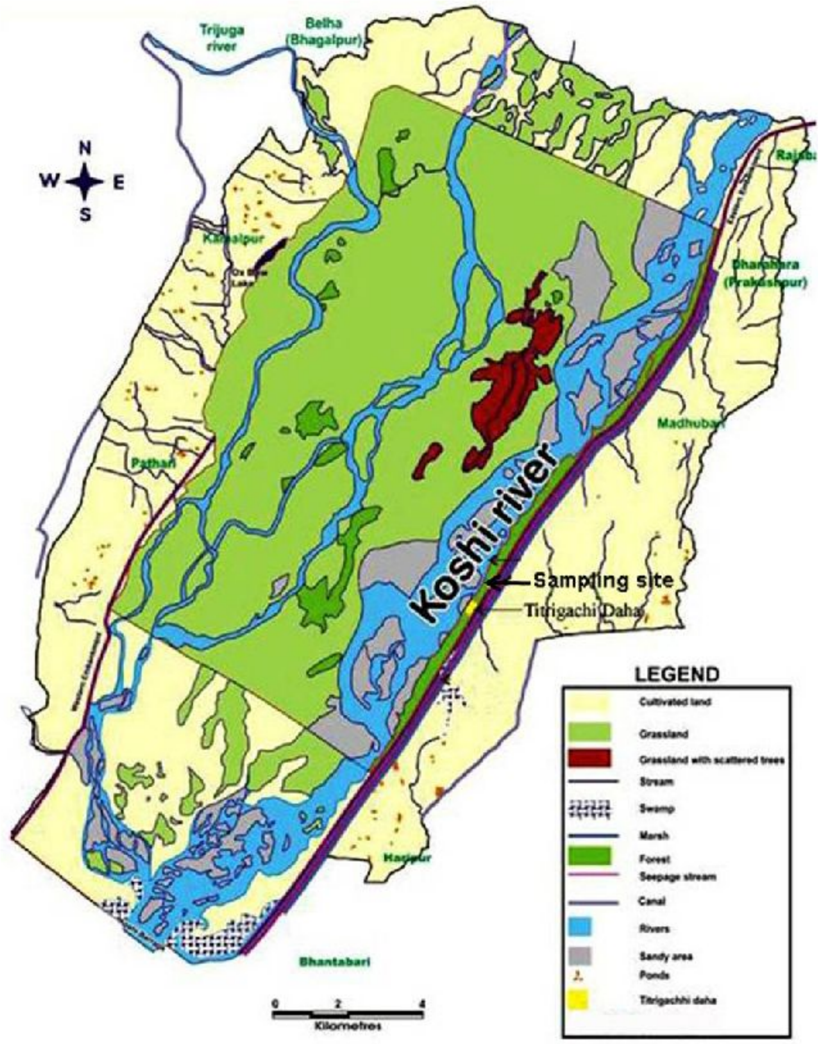

Figure 1. Map showing study site, Kushaha area of Koshi river inside the Koshi Tappu Wildlife Reserve.

The headquarter of Koshi Tappu Wildlife Reserve is also located at Kushaha.

Materials and methods

The physico-chemical parameters were studied from July, 2002 to June, 2004. The water for physico-chemical studies were collected between 8 am and 11 pm, once in every month at regular interval and analysed in the field. However, the BOD test after 5 days incubation in the incubator was done in the laboratory of Post Graduate Campus, Biratnagar. Transparency, air temperature and water temperature were recorded between 12 noon and 1 p.m. For the analysis of physico-chemical parameters, methods of Welch (1952), Michael (1984), Trivedi and Goel (1984), Adoni *et al*. (1985) and APHA (1998) were adopted.

Results

Air temperature

The minimum air temperature was 18.3±0.594°C in the month of January and maximum 32.7±0.427°C in the month of May during the first year study period (July, 2002 to June, 2003) (Tab. 1). The air temperature increased a little in August then decreased from September to January. Again it increased from February to May then a slight decrease was recorded in June and increased a little in July during the first year study period (Tab. 1). Similar pattern of air temperature was observed in the second year study period (July, 2003 to June, 2004) also (Tab 2). The maximum air temperature was 33.1±0.497°C in the month of May and minimum 18.5±0.452°C in the month of January during the second year study period. The air temperature had positive and significant correlation with water temperature (r = 0.9811, P<0.01), free carbon dioxide (r = 0.8259, P<0.01) and biological oxygen demand (r = 0.7196, P<0.01) but inverse and significant correlation with transparency (r = -0.8885, P<0.01), pH (r = -0.5670, P<0.01), dissolved oxygen (r = -0.8424, P<0.01), total alkalinity (r = -0.9264, P<0.01), total hardness (r = -0.6072, P<0.01) and chloride (r = -0.3624, P<0.10) (Tab. 3).

The seasonal variation in air temperature was little higher (30.13°C) in rainy season in comparison to that of summer (29.55°C) and lowest in winter season during the first year study period. During the second year study period, the air temperature was recorded little higher in summer than rainy season and lowest was found in winter (Tab. 4).

Water temperature

The lowest surface water temperature was 14.3±0.550°C in the month of January and highest 29.1±0.320°C in the month of August during the first year study period (July, 2002 to June, 2003). The water temperature increased a little in August then decreased from September to January. Again it increased from February to May and then a slight decrease was recorded in June followed by an increase in July during the first year study period (Tab. 1). Similar pattern of water temperature was observed during the second year study period (July, 2003 to June, 2004) also (Tab. 2). The maximum water temperature was 29.2±0.549°C in the month of August and the minimum 15.2±0.648°C in the month of January during the second year study period (July, 2003 to June, 2004). The water temperature had positive and significant correlation with free carbon dioxide (r = 0.7784, P<0.01) and biological oxygen demand (r =0.7122, P<0.01), but inverse and significant correlation with transparency (r = -0.8498, P<0.01), pH (r = -0. 4981, P< 0.05), dissolved oxygen (r = -0. 8073, P<0.01) total alkalinity (r= -0.9000, P<0.01) and total hardness (r= -0.5763, P<0.01 (Tab.3). Seasonally, water temperature was maximum in summer followed by rainy and winter seasons during the whole study period.

Transparency

It was found that the transparency increased from the month of August to January and then decreased from February to July during the first year (Tab. 1) and the second year study periods (Tab. 2). The maximum transparency was 54.1±0.770 cm in the month of January and minimum 13±0.337 cm in the month of July during the first year study period. During the second year study

Table 1. Air temperature and physico-chemical parameters of water of Koshi river at Kushaha area from July, 2002 to June, 2003 (Mean ± S.D., N = 9).

Parameters	Months											
	Jul.	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**March**	**Apr.**	**May**	**Jun.**
Air temperature (°C)	30.2 ±0.466	32.4 ±0.651	29.6 ±0.523	27.3 ±0.503	23.4 ±0.668	20.7 ±0.442	18.3 ±0.594	26.6 ±0.416	27.5 ±0.485	31.4 ±0.494	32.7 ±0.427	28.3 ±0.552
Water temperature (°C)	27.1 ±0.435	29.1 ±0.320	24.4 ±0.337	24.2 ±0.706	18 ±0.490	17.2 ±0.424	14.3 ±0.550	23.6 ±0.552	25.3 ±0.587	28.2 ±0.618	28.3 ±0.585	24.2 ±0.581
Transparency (cm)	13 ±0.337	14 ±0.320	14.6 ±0.512	29 ±0.854	45 ±0.906	51.3 ±0.822	54.1 ±0.770	43.2 ±0.914	41.2 ±0.799	15 ±0.442	14.5 ±0.508	14.1 ±0.394
P^H	8.1 ±0.240	8.2 ±0.231	7.7 ±0.275	7.9 ±0.283	8.1 ±0.254	8.1 ±0.258	8.2 ±0.231	8.1 ±0.327	7.8 ±0.294	7.6 ±0.298	7.5 ±0.309	7.6 ±0.236
Dissolved oxygen (mg/l)	7.5 ±0.287	8.24 ±0.259	8.72 ±0.352	9.15 ±0.266	9.62 ±0.326	10.41 ±0.238	11.23 ±0.297	10.62 ±0.301	9.52 ±0.326	8.11 ±0.360	7.13 ±0.258	7.11 ±0.335
Free carbon dioxide (mg/ l)	5.63 ±0.320	5.33 ±0.240	5.32 ±0.215	4.72 ±0.349	4.53 ±0.313	4.43 ±0.257	4.34 ±0.287	4.63 ±0.313	4.85 ±0.231	5.32 ±0.290	5.78 ±0.326	5.92 ±0.326
Total alkalinity (mg/ l)	46.32 ±0.721	50.42 ±0.656	56.32 ±0.616	75.46 ±0.659	86.24 ±0.811	107.21 ±0.767	116.52 ±1.045	85.67 ±0.689	69.58 ±0.575	56.55 ±0.579	50.35 ±0.680	48.45 ±0.644
Total hardness (mg/ l)	27.63 ±0.679	37.76 ±0.593	49.65 ±0.514	54.51 ±0.629	57.54 ±0.611	59.45 ±0.515	60.67 ±0.405	63.65 ±0.419	67.55 ±0.463	50.54 ±0.513	43.63 ±0.501	35.45 ±0.443
Chloride (mg/l)	10.25 ±0.216	9.54 ±0.227	7.25 ±0.216	9.83 ±0.283	10.26 ±0.241	11.64 ±0.270	12.15 ±0.260	11.5 ±0.279	10.73 ±0.245	11.33 ±0.254	11.24 ±0.250	10.82 ±0.219
BOD (mg/ l)	0.98 ±0.025	0.95 ±0.045	0.91 ±0.059	0.87 ±0.058	0.83 ±0.050	0.79 ±0.042	0.75 ±0.042	1.13 ±0.043	1.16 ±0.068	1.24 ±0.043	1.35 ±0.062	1.1 ±0.045

Table 2. Air temperature and physico-chemical parameters of water of Koshi river at Kushaha area from July, 2003 to June, 2004 (Mean ± S.D., N = 9).

Parameters	Months											
	Jul.	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**March**	**Apr.**	**May**	**Jun.**
Air temp (°C)	29.2 ±0.426	32.3 ±0.697	28.7 ±0.377	27.00 ±0.339	22.5 ±0.429	19 ±0.459	18.5 ±0.452	26 ±0.539	27.8 ±0.746	32.5 ±0.461	33.1 ±0.497	29 ±0.380
Water temp. (°C)	26.5 ±0.618	29.2 ±0.549	24.3 ±0.616	24.1 ±0.629	18.2 ±0.575	16.1 ±0.556	15.2 ±0.648	23.5 ±0.641	25 ±0.596	27.2 ±0.605	29.1 ±0.789	24.7 ±0.697

Contd....

Table 2-Contd....

Transparency (cm)	14.3 ±0.402	16.3 ±0.727	18.5 ±0.728	29.3 ±0.949	49.4 ±0.844	56.3 ±1.018	62.6 ±0.904	47.8 ±0.813	42.2 ±0.853	25 ±0.811	17 ±0.464	14.4 ±0.403
P^H	8.2 ±0.216	8 ±0.166	7.6 ±0.182	7.8 ±0.188	7.9 ±0.216	8.1 ±0.245	8.3 ±0.216	8.1 ±0.182	7.9 ±0.210	7.7 ±0.290	7.6 ±0.141	8 ±0.210
DO (mg/l)	7.52 ±0.204	7.91 ±0.242	8.63 ±0.249	9 ±0.230	9.53 ±0.294	10.2 ±0.301	11.3 ±0.258	10.11 ±0.246	8.7 ±0.240	8.36 ±0.157	7.34 ±0.226	7.22 ±0.248
Free CO_2 (mg/l)	5.74 ±0.179	5.22 ±0.209	5.14 ±0.157	4.5 ±0.230	4.4 ±0.249	4.23 ±0.236	4.15 ±0.179	4.54 ±0.195	4.83 ±0.226	5.48 ±0.204	5.62 ±0.244	5.84 ±0.279
Total alkalinity (mg/l)	48.45 ±0.684	52.5 ±0.621	53.54 ±0.801	67.23 ±0.756	86.13 ±0.753	104.34 ±0.723	118.62 ±1.090	89.35 ±0.793	71.56 ±0.904	58.62 ±0.651	52.53 ±0.719	49.72 ±0.779
Total hardness (mg/l)	29.34 ±0.603	40.83 ±0.648	47.63 ±0.529	52.82 ±0.511	60.65 ±0.585	62.46 ±0.582	63.52 ±0.614	65.12 ±0.635	68.11 ±0.628	53.14 ±0.639	43.52 ±0.511	37.34 ±0.636
Chloride (mg/l)	11.25 ±0.216	9.82 ±0.174	7.94 ±0.164	9.56 ±0.231	10.57 ±0.210	12.29 ±0.260	12.75 ±0.229	11.64 ±0.216	10.42 ±0.219	12.54 ±0.195	11.4 ±0.188	11.5 ±0.193
BOD (mg/l)	0.95 ±0.021	0.92 ±0.027	0.88 ±0.066	0.86 ±0.049	0.84 ±0.037	0.81 ±0.034	0.65 ±0.039	0.98 ±0.034	1.12 ±0.042	1.25 ±0.057	1.33 ±0.030	0.99 ±0.048

Table 3. Pearson's correlation coefficient (r) for air temperature and physico-chemical parameters of water of Koshi river at Kushaha area during July, 2002 to June, 2004 (N = 24, d.f. = 22).

Parameters	**Water temp. (°C)**	**Transp. (cm)**	**P^H**	**DO (mg/L)**	**Free CO_2 (mg/L)**	**Total alkalinity (mg/L)**	**Total hardness (mg/L)**	**Chloride (mg/L)**	**BOD (mg/L)**
Air temp. (°c)	0.9811*	-08885*	-0.5670*	-0.8424*	0.8259*	-0.9264*	-0.6072*	-0.3624***	0.7196*
Water temp. (°c)		-0.8498*	-0.4981**	-0.8073*	0.7784*	-0.9000*	-0.5763*	-0.3256	0.7122*
Transparency (cm).			0.5225*	0.9151*	-0.9137*	0.9561*	0.8495*	0.4666**	-0.4829**
P^H				0.5491*	-0.4909**	0.5577*	0.1488	0.3184	-0.6496*
DO (mg/l)					-0.9308*	0.9404*	0.8144*	0.2870	-0.5717*

Contd....

Table 3-Contd....

Free CO_2 (mg/l)	-0.9004*	-0.8287*	-0.1885	0.6214*
Total alkalinity (mg/l)		0.7641*	0.4700**	-0.5706*
Total hardness (mg/l)			0.2521	-0.1794
Chloride (mg/l)				0.1625

* Significant at 1% level (P<0.01), ** significant at 5% level (P<0. 05), *** significant at 10 % level (P<0.10); Values not marked denote non-significant correlation.

Table 4. Seasonal variations in air temperature and physico-chemical Parameters of water of Koshi river at Kushaha area during the first year (July, 2002 to June, 2003) and the second year (July, 2003 to June, 2004) study Periods.

Parameters	**Year I**			**Year II**		
	Summer	**Rainy**	**Winter**	**Summer**	**Rainy**	**Winter**
Air temp. (°C)	29.55	30.13	22.43	29.85	29.8	21.75
Water temp. (°C)	26.35	26.2	18.43	26.2	26.18	18.4
Transparency (cm)	28.48	13.93	44.85	33	15.88	49.4
P^H	7.75	7.9	8.08	7.83	7.95	8.03
DO (mg/l)	8.85	7.89	10.10	8.63	7.82	10.01
Free CO_2 (mg/l)	5.15	5.55	4.51	5.12	5.49	4.32
Total alkalinity (mg/l)	65.54	50.38	96.36	68.02	51.05	94.08
Total hardness (mg/l)	56.34	37.62	58.04	57.47	38.79	59.86
Chloride (mg/l)	11.2	9.47	10.97	11.5	10.13	11.29
BOD (mg/l)	1.22	0.99	0.81	1.17	0.94	0.79

period, the maximum transparency was 62.6±0.904 cm in the month of January and minimum 14.3±0.402 cm in the month of July. The transparency had positive and significant correlation with pH (r =0.5225, P<0.0.1), dissolved oxygen (r =0.9151, P<0.01), total alkalinity (r = 0.9561, P<0.01), total hardness (r = 0.8495, P<0.01) and chloride (r = 0.4666, P<0.05), but inverse and significant correlation with free carbon dioxide (r = -0.9137, P<0.01) and biological oxygen demand (r = -0.4829, P<0.05) (Tab. 3). The maximum value of transparency was in winter followed by summer and rainy seasons during the first and the second year study periods.

pH

The pH of water of the Koshi river increased a little in August then a slight decrease was recorded in September. Again it increased from October to January then decreased from February to May and increased from June to July during the first year study period (Tab. 1). The minimum pH was 7.5±0.309 in the month of May and maximum 8.2±0.231 in August and January, respectively during the first year study period. During the second year study period, it decreased from August to September then increased from October to January. Again it decreased from February to May then increased from June to July (Tab. 2). The minimum pH was 7.6±0.182 and 7.6±0.141 in the month of September and May, respectively and maximum 8.3±0.216 in January during the second year study period. pH had positive and significant correlation with dissolved oxygen (r = 0.5491, P<0.01) and total alkalinity (r = 0.5577, P<0.01) but inverse and significant correlation with free carbon dioxide (r = -0.4909, P<0.05) and biological oxygen demand (r = -0.6496, P<0.01) (Tab. 3). The pH was highest in winter followed by rainy and summer seasons during the first and the second year study periods.

Dissolved oxygen

The dissolved oxygen increased from July to January and decreased from February to June during the first year (Tab. 1) and the second year study periods (Tab. 2). The maximum dissolved oxygen was 11.23±0.297 mg/l in the month of January and the minimum 7.11±0.335 mg/l in the month of June during the first year study period. In the second year study period, the maximum dissolved oxygen was 11.3±0.258 mg/l in the month of January and minimum 7.22±0.248 mg/l in the month of June. The dissolved oxygen showed positive and significant correlation with total alkalinity (r = 0.9404, P<0.01) and total hardness (r = 0.8144, P<0.01) but inverse and significant correlation with free carbon dioxide (r = -0.9308, P<0.01) and biological oxygen demand (r = -0.5717, P<0.01) (Tab. 3). The maximum dissolved oxygen was in winter followed by summer and rainy seasons during the first and the second year study periods.

Free carbon dioxide

The free carbon dioxide decreased from July to January then increased from February to June during the first year (Tab. 1) and the second year study periods (Tab. 2). The maximum free carbon dioxide was 5.92±0.326 mg/l in the month of June and minimum 4.34±0.287 mg/l in the month of January during the first year study period. During the second year study period, the maximum free carbon dioxide was 5.84±0.279 mg/l in the month of June and minimum 4.15±0.179 mg/l in the month of

January. Free carbon dioxide showed positive and significant correlation with biological oxygen demand (r = 0.6214, P<0.01) but inverse and significant correlation with total alkalinity (r = -0.9004, P<0.01) and total hardness (r = -0.8287, P<0.01) (Tab. 3). Maximum value of free carbon dioxide was in rainy season followed by summer and lowest in winter season during the first and the second year study periods.

Total alkalinity

The total alkalinity increased from August to January and decreased from February to July during the first year (Tab. 1) and the second year study periods (Tab. 2). The maximum total alkalinity was 116.52±1.045 mg/l in January and minimum 46.32±721 mg/l in July during the first year study period. During the second year study period, the maximum total alkalinity was 118.62±1.090 mg/l in the month of January and minimum 48.45±0.684 mg/l in the month of July. It had positive and significant correlation with total hardness (r = 0.7641, P<0.01) and chloride (r = 0.4700, P<0.05) but inverse and significant correlation with biological oxygen demand (r = -0.5706, P<0.01) (Tab. 3). The maximum total alkalinity was in winter followed by summer and rainy seasons during the whole study period.

Total hardness

The total hardness increased from August to March and decreased from April to July during the first year (Tab. 1) and the second year study periods (Tab. 2). The maximum total hardness was 67.55±0.463 mg/l in March and minimum 27.63±0.679 mg/l in July during the first year study period. During the second year study period, the maximum total hardness was 68.11±0.628 mg/l in March and minimum 29.34±0.603 mg/l in July. It had positive and significant correlation with transparency (r = 0.8495, P<0.01), dissolved oxygen (r = 0.8144, P<0.01) and total alkalinity (r = 0.7641, P<0.01) and inverse and significant correlation with air temperature (r = -0.6072, P<0.01), water temperature (r = -0.5763, P<0.01), and free carbon dioxide (r = -0.8287, P<0.01) (Tab. 3). The maximum total hardness was in winter followed by summer and rainy seasons during the whole study period.

Chloride

The maximum chloride was 12 .15±0. 260 mg/l in January and minimum 7.25±0.216 mg/l in September during the first year study period (Tab. 1). During the second year study period, the maximum chloride was 12.75±0.229 mg/l in the month of January and minimum 7.94±0.164 mg/l in the month of September (Tab. 2). It had positive and significant correlation with transparency (r = 0.4666, P<0.05) and total alkalinity (r = 0.4700, P<0.05), and inverse and significant correlation with air temperature (r = -0.3624, P<0.10) (Tab. 3). The maximum value of chloride was in summer followed by winter and minimum in rainy season during the first and the second year study periods.

Biological oxygen demand

The biological oxygen demand decreased from July to January and increased from February to May. Again it decreased a little in June during the first year (Tab. 1) and second year study periods (Tab. 2). The maximum biological oxygen demand was 1.35±0.062 mg/l in May and minimum 0.75±0.042 mg/l in January during the first year study period. During the second year study period, the maximum biological oxygen demand was 1.33±0.030 mg/l in the month of May and minimum 0.65±0.039 mg/l in January. It had positive and significant correlation with air temperature ($r = 0.7196, P<0.01$), water temperature ($r = 0.7122, P<0.01$) and free carbon dioxide ($r = 0.6214, P<0.01$) but inverse and significant correlation with transparency ($r = -0.4829$ $P<0.05$), pH ($r = -0.6496, P<0.01$), dissolved oxygen ($r = -0.5717, P<0.01$) and total alkalinity ($r = -0.5706, P<0.01$) (Tab. 3). The maximum value of biological oxygen demand was in summer followed by rainy and winter seasons during the first and the second year study periods (Tab. 4).

Discussion

The highest air temperature was recorded in the month of May (Tabs. 1, 2). When data on monthly air temperature of the first year (July, 2002 to June, 2003) and the second year (July, 2003 to June, 2004) study periods were pooled in seasonal values, very little difference observed in rainy and summer season (Tab. 4) due to its geographical location. Air temperature showed positive and significant correlation with water temperature (Tab. 3). Chakraborty *et al*. (1959), Kant and Anand (1978) and Rawat *et al*. (1995) also obtained strong positive significant correlation between air and water temperatures.

Generally, water temperature is influenced by air temperature and intensity of solar radiation. It was highest in summer and lowest in winter (Tab. 4). Highest value recorded in summer might be due to high air temperature and greater light penetration and comparatively low volume of water than rainy season. The water temperature showed positive and significant correlation with free carbon dioxide and biological oxygen demand but had inverse and significant correlation with transparency, pH, dissolved oxygen, total alkalinity and total hardness. Bose and Gorai (1993) reported negative significant correlation between water temperature and dissolved oxygen. Welch (1952) and Munawar (1970) have observed that shallower the water body more quickly it reacts to the change in the temperature.

The maximum Secchi disc transparency was recorded in winter followed by summer and rainy seasons during whole study period (Tab. 4). The maximum transparency was in winter due to lesser amount of suspended organic and inorganic materials and absence of rain. Transparency is influenced mainly by suspended organic matter (Green, 1974). Higher transparency during winter months was recorded by Singh (1990), Rawat *et al.* (1995) and Mishra *et al*. (1999). In this study minimum transparency was recorded in the rainy season may be due to more sand particles and colloidal particles carried by the rain water. Similar trends were observed by Singh (1995) and Mishra *et al*. (1998).

The maximum pH of present study was in winter season followed by rainy and summer seasons (Tab. 4). The maximum pH in winter season may be attributed to algal blooms because Roy (1955) had shown that the higher pH is associated with the phytoplankton maxima. The minimum pH recorded in summer may be due to low photosynthesis. Several workers have reported low pH during the low photosynthesis due to the formation of carbonic acid (Hannan and Yong, 1974; Cabecadas and Brogueira, 1987; Bais *et al*., 1995). But, Gautam (1990) reported highest pH in summer and lowest in rainy season. The pH showed positive and significant correlation with dissolved oxygen and total alkalinity. Rawat *et al*. (1995) reported positive correlation with total alkalinity ($r = 0.523$, $P<0.05$) and inverse correlation with water temperature.

The maximum dissolved oxygen found in winter season may be due to low temperature. Similar observations were made by Moitra and Bhattacharya (1965). The minimum dissolved oxygen was found in summer due to high temperature, and higher microbial demand of oxygen for decomposition of suspended organic matter (Bhowmick and Singh, 1985; Palharya and Malviya, 1988). Elmore and West (1961) stated that an increase in temperature of water results in the decrease of dissolved oxygen content of water. The dissolved oxygen showed inverse and significant correlation with water temperature, free carbon dioxide and biological oxygen demand. Bose and Gorai (1993) also reported inverse and significant correlation of dissolved oxygen with water temperature. Jindal and Kumar (1993) reported inverse correlation of dissolved oxygen with water temperature.

In this study the minimum free carbon dioxide was found in winter season. Pahwa and Mehrotra (1966), Gautam (1990) and Pandey and Lal (1995) also found minimum free carbon dioxide in winter season. Free carbon dioxide of water showed positive and significant correlation with water temperature and biological oxygen demand, and inverse and significant correlation with dissolved oxygen (Tab. 3). Pahwa and Mehrotra (1966) observed inverse correlation of free CO_2 with dissolved oxygen.

The total alkalinity observed was maximum in winter season due to high pH. Chakraborty *et al*. (1959), Singh (1990) and Mishra *et al*. (1998) also reported maximum total alkalinity during winter. Water bodies having total alkalinity from 40 to 90 mg/l is considered as medium productive and above 90 mg/l as highly productive (Jhingran, 1991). This investigation showed that the study area is suitable for aquatic production.

Maximum total hardness in winter season might be due to low volume of water and slow current of water. Similar results were obtained by Misra *et al*. (1999). Minimum quantity in rainy season may be due to more dilution of water (Patralekh, 1994). Ruttner (1953) also recorded similar relationship.

Seasonally, the maximum chloride content was recorded in summer followed by winter and rainy seasons (Tab. 4). The maximum quantity of chloride recorded in summer season may be due to low volume of water, high temperature and high rate of decomposition of organic matters. Chloride concentration indicates the presence of organic waste of animal origin (Thresh *et al*., 1949). Munawar (1970) has suggested that higher concentration of chloride in water is an index of pollution of animal origin and there is a direct relation between chloride concentration and pollution level.

The maximum BOD was recorded in summer followed by rainy and winter seasons (Tab. 4). The maximum BOD obtained in summer may be due to low volume of water and high content of organic matter whereas minimum obtained in winter may be due to low temperature and retarded microbial activity for the decomposition of organic matters. Similar observations were also made by Singh (1995). Ray and David

(1966) opined that high BOD value indicates organic waste pollution.

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