DISCUSSION

The highest air temperature was recorded in the month of May at all the sites (Tables 2, 3, 6, 8, 9, 11 and 12) except at Site 2 which had highest air temperature in the month of August of the first year study period (Table 5). When data on monthly air temperature of the whole study period (July 2002 - June 2004) were pooled in seasonal values, the rainy season showed highest air temperature at all the sites (Table 18). Because gradual increase in air temperature was noticed during summer months (February, March, April and June). The summer temperature (30.04 °C) was moderate in this region due to its geographic condition. Air temperature showed positive and significant correlation with water temperature at all the sites (Tables 4, 7, 10 and 13). Chakaraboty *et al.* (1959), Kant and Anand (1978) and Rawat *et al.* (1995) also obtained strong positive significant correlation between air and water temperatures. The air temperature showed significant difference among sites at 5 % significance level and significant difference among seasons at 1 % significance level (Table 19).

Generally, water temperature is influenced by air temperature and intensity of solar radiation. It was highest in summer at all the sites and lowest in winter (Table 18). Highest value was recorded in summer might be due to high air temperature and greater light penetration. Though the high air temperature appeared in rainy season, a little lower water temperature was recorded at that time in comparison to that during summer. It might be due to high turbidity, high volume of water and greater velocity of water in rainy season. The water temperature showed positive and significant correlation with free carbon dioxide and biological oxygen demand at all the sites but had inverse and significant correlation with transparency, P^H , dissolved oxygen, total alkalinity and total hardness at all the sites. 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 water temperature was insignificantly different among sites but significantly different among seasons at 1 % significance level (Table 20).

The maximum secchi disc transparency was recorded in winter followed by summer and rainy seasons at all the sites (Table 18). 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 soil carried by the rain water. Similar trends were observed by Singh (1995), Rawat *et al.* (1995), and Mishra *et al.* (1998). The transparency of water was insignificantly different among sites and seasons at 5 % significant level (Table 21).

The maximum P^H of present study was in winter season followed by rainy and summer seasons at all the sites (Table 18). The maximum P^H in winter season may be attributed to algal blooms because Hutchinson *et al.* (1929) and Roy (1955) have shown that the higher P^H is associated with the phytoplankton maxima. The minimum P^H recorded in summer may be due to low photosynthesis. Several workers have reported low P^H 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 P^H in summer and lowest in rainy season. The P^H showed positive and significant correlation with dissolved oxygen at all the sites. It had positive and significant correlation with total alkalinity at Site 1 and Site 2 but had positive correlation with those of Site 3 and Site 4. It was inverse and significantly correlated with free carbon dioxide and biological oxygen demand at all the sites (Tables 4, 7, 10 and 13). Rawat *et al.* (1995) reported positive correlation with total alkalinity ($r = 0.523$, $P < 0.05$) and inverse correlation with water temperature. The P^H showed significant difference among seasons at 1 % significance level (Table 22).

The dissolved oxygen of the study sites varied between 5.11 $\pm$0.223 mg/L and 11.3 $\pm$0.258 mg/L during the study period. It was recorded minimum in the month of May of the second year study period at Site 3 (Table 9) and maximum in the month of January of the second year study period at Site 1 (Table 3). The maximum dissolved oxygen was recorded in winter season followed by rainy and summer seasons at all the sites except at Site 1 because at this site it was maximum in winter season followed by summer and rainy seasons (Table 18). 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 for oxygen in decomposition of suspended organic matter (Bhowmick and Singh, 1985; Palharya and Malvia, 1988). Elmore (1961) stated that an increase in temperature of water resulted in the decrease of dissolved oxygen content of water. Dissolved oxygen content showed positive and significant correlation with total alkalinity and total hardness at all the sites. It was positively correlated with chloride at Site 1 and Site 4 and positively and significantly correlated with chloride at Site 2 and Site 3. It showed inverse and significant correlation with water temperature, free carbon dioxide and biological oxygen demand at all the sites. 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. According to McColl (1972) the relation between water temperature and dissolved oxygen is not so significant because the production and consumption of oxygen takes place simultaneously. The dissolved oxygen was recorded significantly different among sites and seasons at 1 % significance level (Table 23).

The maximum free carbon dioxide was recorded in summer season followed by rainy and winter season at Site 2, Site 3 and Site 4 but at Site 1, it was maximum in rainy season followed by summer and winter seasons (Table 18). The maximum free carbon dioxide was recorded in summer, it may be due to high temperature, high rate of decomposition of organic matter, low volume of water etc. Michael (1969) stated that the concentration of carbon dioxide is directly correlated with the amount and nature of biological activity in water. In this study the minimum free carbon dioxide was found in winter season. Pahwa and Mehrotra (1966), Ray *et al.* (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 at all the sites (Tables 4, 7, 10 and 13). Pahwa and Mehrotra (1966) observed inverse correlation of free CO_2 with dissolved oxygen. The free CO_2 showed significant difference among the sites and the seasons at 1 % significance level (Table 24).

The total alkalinity was found maximum in the month of January at all the sites. It was found maximum 125.59 $\pm$1.138 mg/L at Site 3 in the first year study period (Table 8). Seasonally the maximum total alkalinity was found in winter season followed by summer and rainy seasons at all the sites (Table 18). It was found maximum in winter season due to high P^H. 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. Total alkalinity showed positive and significant correlation with total hardness and chloride at all the sites. Barat and Jha, (2002) also reported positive and significant correlation of total alkalinity with hardness. The total alkalinity was significantly different among sites at 5 % significance level and significantly different among seasons at 1 % significance level (Table 25).

The maximum total hardness of water was 83.45 $\pm$0.584 mg/L at Site 4 (Table 12) in the month of March of the second year study period and minimum 27.63 $\pm$0.679 mg/L in the month of July of the first year study period at Site 1 (Table 2). The maximum total hardness was in winter season followed by summer and rainy seasons at all the sites (Table 18). The 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. It showed positive and significant correlation with total alkalinity at all the sites. The total hardness was recorded significantly different among seasons and sites at 1 % significance level (Table 26).

The chloride content of water of the study sites varied between 7.25 $\pm$ 0.216 mg/L and 18.73 $\pm$0.205 mg/L during the study period. The minimum chloride was recorded in September of the first year study period at Site 1 (Table 2) and maximum in December of the first year study period at Site 2 (Table 5). Seasonally the maximum chloride content was recorded in summer followed by winter and rainy seasons at Site 1 and Site 4 but at Site 2 and Site 3 maximum was in winter followed by summer and rainy seasons (Table 18). The maximum quantity of chloride recorded at Site 1 and Site 4 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.

Ganapati (1941, 1943), and Swarup and Singh (1979) also reported an increase in chloride during summer. Minimum quantity of chloride recorded in rainy season might be due to dilution by rain water. But at Site 2 and Site 3 maximum chloride was recorded in winter season which might be due to more contamination by organic matters. Klein (1957) pointed out a direct relationship between amount of chloride and level of pollution. Chloride showed positive and significant correlaton with total alkalinity at all the sites. The chloride content was significantly different among sites at 1 % significance level (Table 27).

The BOD of water of the study sites varied between 0.65 $\pm$0.039 mg/L and 2.36 $\pm$0.082 mg/L during the study period. It was maximum in the month of May of the second year study period at Site 4 (Table 12) and minimum in the month of January of the second year study period at Site 1 (Table 3). The maximum BOD was recorded in summer followed by rainy and winter seasons at all the sites (Table 18). 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 Devid (1966) opined that high BOD value indicates organic waste pollution.

BOD showed positive and significant correlation with air temperature, water temperature and free CO_2 and inverse and significant correlation with P^H and dissolved oxygen at all the sites (Table 4, 7, 10 and 13). Ray and David (1966), and Barat and Jha (2002) also reported inverse correlation of BOD with dissolved oxygen. The BOD was recorded significantly different among seasons at 1 % significance level (Table 28).

Macrophytes are the main components of aquatic ecosystem as they form the important habitat for amphibians, reptiles, fishes, molluscs, waterfowls etc. In recent years macrophytes have been considered suitable for both secondary and tertiary treatments of water bodies and thus provide a cheap and relatively simple alternative. Aquatic plants can absorb significant amount of nutrients and other elements directly either through root or entire plant surface. Boyd (1970) and Steward (1970) demonstrated the nutrient removal by aquatic plants. Surface weeds like water hyacinth have been shown to have a great potential for treating waste water. Vascular macrophytes are involved in the biogeochemical cycling of both nutrient and non essential elements in many aquatic ecosystems.

The total recorded aquatic macrophytes of Nepal are 240 species belonging to 124 genera and 58 families (Shrestha, 1999). During the study period, 65 species belonging to 53 genera and 32 families were recorded in the Koshi Tappu Wildlife Reseve and its surroundings which represent 27.08%, 42.74% and 55.17% of total aquatic plants of Nepal in terms of species, genera and family respectively. It was observed that *Typha angustifolia, Eichhornia crassipes, Nelumbo nucifera, Alternanthera philoxeroides, Phragmites karka, Saccharum spontaneum* are the dominant plant species in this study area.

Exotic weeds *Alternanthera philoxeroids* and *Eichhornia crassipes* were found in abundance in some areas in the wetlands. The growth rate and spread of the exotic weeds need to be monitored regularly. Local people are also using the aquatic macrophytes for different purposes. If these trends continue at the current rate the aquatic macrophytes will decrease in near future and that will ultimately affect the abundance of insects, molluscs, fishes, amphibians, reptiles and mammals of this area.

The annelids are important for maintaining the healthier ecosystem. Two species of annelids were identified from the study area.

The aquatic arthropods constitute an important part of biota of freshwater communities. They are of great economic importance both as natural food for fish and as indicator for identifying ecological characteristic of streams. Some beetles and bugs also act as scavengers in keeping the water fresh by removing decayed leaves and other materials. The present study recorded 23 species of aquatic arthropods. Mainly *Chironomous* larvae, *Culex* larvae, *Anopheles* larvae, *Hydrometra* sp., *Gerris* sp. and *Macrobrachium* sp. were abundant in the study area.

Molluscs, in general, have been of interest to mankind due to their commercial, nutritive, aesthetic and pathological importance since long time. Diverse species of molluscs make their habitat in the wetlands. Suitable temperature, higher dissolved oxygen and thick macrophytes are the necessary conditions for the abundance of molluscs. The study area is a suitable habitat for the molluscs due to rich diversity of aquatic macrophytes.

Thick vegetation of *Ceratophylum, Eichhornia, Hydrilla* and *Potamegeton* provide food, shelter and protection to the gastropods. Higher levels of calcium, bicarbonate, total hardness of water and exchangeable calcium and bicarbonate of soil also directly and indirectly are responsible for the shell formation of gastropods. Dudani *et al.* (1988) confirmed the abundance of gastropods due to aquatic vegetation and higher levels of some physico- chemical characteristics of water.

The present study reported 16 species of molluscs from the wetlands of Koshi Tappu area. Many local people depend on the molluscs due to the poor economic status, unemployment and traditional food habit (Table 33). They collect molluscs day by day and sell in the market. These practices definitely reduce the diversity and abundance of mollusc species. Besides human beings, many waterfowls also consume molluscs. So, the sustainable use of molluscs is essential.

Some harmful molluscs were also recorded in the study area, among them the land mollusc *Achatina* is most serious pest of crops, vegetables and marshy plants (Table 34).

Subba (2003) reported ten species of molluscs from Ghdaghodi Tal area, Nepal. Subba and Ghosh (2000) reported 25 species of molluscs from nine districts of Eastern Nepal.

The wetlands of Koshi Tappu wildlife Reserve and its surrounding areas are rich in fish diversity. Altogether 92 species of fish belonging to 54 genera and 25 families were recorded from this area. A total of 179 species of fishes belonging to 30 families have been reported from Nepal (Shrestha, 1994). The study area represents 51.39 % and 83.33% of total fishes of Nepal in terms of species and family respectively. Among the collected species, 9 species (*Aspidoparia jaya, Aspidoparia morar, Crossocheilus latius, Puntius sophore, Puntius ticto, Channa punctatus, Chana gachua, Xenentodon cancila, Badis badis*) (Table 35) were found most commonly throughout the year. *Badis badis* is an ornamental fish. It has export value.

(Edds, 1986) reported 113 species of fishes belonging to 10 orders and 23 families from Royal Chitwan National Park. Jha and Shrestha (1986) reported 57 species of fishes from the Karnali river, western Nepal. Bhatta and Shrestha (1973) observed 27 species of fishes from the Mahakali river. The study area is rich in fish diversity because it includes the Koshi river and various types of wetlands. The Koshi river originates from the Himalayan region and passes to the India from the Terai regions of Nepal. So, it consist Hill stream fishes and Terai fishes.

Menon (1949) recorded 52 species of fish from Koshi river. Afterwards he added 69 more fishes in his previous list (Menon, 1962). Shrestha (1980) (cited in Shrestha, 1990) recorded 108 fish species from Koshi river. The present study recorded 92 species belonging to 25 families of fish from the reserve and its surroundings. This clearly indicated that diversity of fish species has decreased recently. This might be due to over fishing by the landless fishermen of this area as they are dependent on fishing in Koshi river, oxbow lakes, seepage stream and marshes. The fishermen fish in groups of 10-12 people with cast nets, mesh nets and sometimes with gill nets (Suwal, 1994). They also use poison for fishing in wetland areas. They use other indigenous fishing devices such as bausi, shoat, chanch and dhasa. In shallow marshes fishes are caught by hands.

Over-fishing, pollution, poisoning, dynamiting and introduction of exotic fishes are outlined as possible threats to the native fish species (Edds, 1986).

Only 8 species of amphibians and 15 species of reptiles were found during the whole study period (Table 36). A total of 52 species of amphibians and 125 species of reptiles have been recorded in Nepal (Schleich and Kaestle, 2002). The present study recorded 15.38 % of total amphibians of Nepal and 12 % of total reptiles of Nepal. No work has been carried previously on the amphibia in the wetlands of Koshi Tappu Wildlife Reserve area. From this study it appeared that the populations of *Varanus bengalensis, Varanus flavescens, Asiatic rock python* and turtle had decreased due to poaching for their leather, meat and medicinal uses. The *Naja naja* is deadly poisonous so the people generally kill this animal when they see. Therefore, it can be observed very rarely. The freshwater crocodile, *Crocodylus palustris* has been reported from Koshi river by Shrestha (1994). Detailed investigation is needed to assess the diversity of amphibians in this area.

Regarding aves, Koshi Tappu Wildlife Reserve and its surrounding areas are very suitable due to the presence of different wetlands and aquatic macrophytes. Baral (2000) reported altogether 461 species representing 58 families from this region. The present study was focused only to the water birds. This study revealed 11.89 %, 51.81 %, and 53.47 %, species of birds of total birds of Nepal, total wetlands' birds of Nepal and total terai wetlands' birds of Nepal, respectively. Detailed study of investigation is needed to ascertain the present status of water bird diversity in Koshi Tappu area.

The maximum species was recorded in winter season. The pintail was most abundant with around 3,000 individuals at its peak season. Then the common teal were around 900 individuals in its peak season. Lesser Whistling Teal, Gadwall and Cotton Teals were also numerous. Most other duck species occurred generally below 400 in numbers. A few rare species such as Falcated Teal and Barheaded Goose were also observed in small numbers.

The number of birds recorded during this study period was compared with earlier records given by Scott in 1989. Although there were limitation in the extent to which such comparisons could be made because the exact areas and time surveyed by Scott were not given, however the magnitude of the differences strongly suggest that there may have been dramatic reduction in the abundance of many wetland bird species. In particular, Pintail, Garganey, Lesser Whistling Teal, Ruddy Shelduck seem to have decreased considerably in numbers.

The waterfowl have been benefited from the construction of the Koshi barrage through the development of a large expanse of water and extensive marshy lands. However, the increased frequency of flooding has negatively affected a large number of breeding species, notably the herons and storks.
The habitat of birds in this region is being destroyed due to many factors mainly accumulation of silt by erosion, excessive harvesting of macrophytes by the local people and accumulation of pollutants in the wetlands from different sources.

The present study showed decreasing trend of bird species from previous record. There may be several reasons, one of them may be that birds have changed their migration route, although this seems unlikely. The other reasons are hunting, poaching, trapping in the migration route and in the breeding areas. Besides these possible reasons nowadays the human disturbances, increased food shortage, and loss of habitat in the Koshi Tappu area may be the strong reasons for the decrement of bird species than previous records.

The present study area is also suitable habitat for different species of mammals due to the presence of wetlands and forest area. Altogether, 21 species of mammals were recorded during this study period (Table 38). According to the local people, the Koshi Tappu area was covered with dense riverine forest and tall grasses in the past where large carnivores, such as Bengal tiger (*Panthera tigris*) and leopard (*Panthera pardus*) were abundant. But now these mammals could not be observed. However, this area contains Nepal's last surviving population of wild water buffalo (Heinen, 1993). Gaur (*Bos gaurus*) and Nilgai (*Boselaphus tragocamelus*) were not found. Their presence was reported on earlier occasion (Suwal, 1994). The Gangetic dolphin (*Platanista gangetica*) was observed in Koshi barrage area. Besides the local domesticated elephants, the other Asiatic elephants visit here from India during summer months. According to the local information, except the wild water buffalo, other various species of mammals and their number has decreased in this area after the establishment of reserve and clearing of forest in its surroundings.