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Hydrological characteristics and flood plain vegetation of human impacted wetlands: A case study from Okhla Bird Sanctuary, National Capital Region, India

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ABSTRACT

Yamuna River has been subjected to severe anthropogenic pressures such as water abstraction, discharge of wastewater, development activities on river floodplains, deforestation in the river basin resulting in reduced flow, loss of habitat, deterioration of water quality and loss of biological diversity. We studied hydrological characteristics such as river flow, water depth and quality and floodplain vegetation characteristics of Okhla Bird Sanctuary (OBS), a human modified floodplain wetland formed due to the construction of Okhla barrage across the Yamuna River in National Capital Region (NCR), on the Delhi-Uttar Pradesh border. The flow data for Yamuna was collected from Delhi Jal board and irrigation department of Uttar Pradesh. Study indicates reduced flow in the river downstream Wazirabad with no release of water in the summers of 2006 and 2010. For bathymetry, GARMIN 160 C Fish Finder was used after dividing study area into 50 m x 50 m grids. About 65% area had depth less than 2 m indicating more of shallower areas. Results for water quality analysis show a dissolved oxygen level at 1.6 ± 0.84 mgl^{-1}, Biological and Chemical Oxygen demand at 16.72 ± 4.28 mgl^{-1} and 39.8 ± 7.71 mgl^{-1} respectively, indicating a high organic load in the river. The Sanctuary is facing serious threats from the rapid proliferation of *Typha angustifolia* and *Eichhornia crassipes* which were dominant species in shallow water and open water habitats, respectively. Thus, the remaining Yamuna river flood plain in the NCR, Delhi should be declared as ecologically sensitive area and appropriate measures should be taken to maintain its integrity.

Key words: river flow, water depth, water quality, floodplain vegetation, Yamuna river, river restoration

INTRODUCTION

Increasing human population and needs have resulted in hydrological alteration and environmental degradation of aquatic habitats on a global scale (Dudgeon, 2000; Tharme, 2003; King *et al.*, 2003). Various threats to rivers include flow alteration, pollution, drainage-basin alteration and overharvesting of various aquatic resources (Dudgeon, 2000). Alteration of river flow due to dams and barrages results in seasonal discharge of water influencing the biota including floodplain vegetation and changing land-water interactions (Poff *et al.*, 1997; Dudgeon, 2000; Buijse *et al.*, 2002); amplifying various other problems *e.g.* it may concentrate pollution in the downstream channel (Dudgeon, 2000). A number of factors influence composition and success of floodplain vegetation community, spatial distribution of a plant species and succession including hydrological regimes (Junk *et al.*, 1989; Nilsson *et al.*, 1989; Stromberg *et al.*, 1997; Lytle and Merriti, 2004; Stromberg *et al.*, 2007), sediment's organic content and nutrient levels (Pearsall, 1920; Misra, 1938; Macan, 1977; Barko and Smart, 1983; Barko *et al.*, 1986; Lougheed *et al.*, 2001; James *et al.*, 2005; Tamot and Sharma, 2006) and water depth (Hudon, 2004). Depth has a key role as a variable in various impacts of construction of a reservoir on environment as it acts on the aquatic system hydrodynamics, controlling physical-chemical and biological properties of the system (Alcantara, 2009). Increased nutrient loads in freshwater bodies from various external organic and inorganic sources have been attributed by several workers to be responsible for bringing change in vegetation composition (Bugenyi and Balirwa, 1998; Chukwuka *et al.*, 2008; Gichuki *et al.*, 2009). Excessive growth of certain plant species results in increased sediment accumulation, decreased dissolved oxygen levels and reduced seed banks resulting in reduction of re-vegetation potential of invaded water body (de Winton and Clayton, 1996; Perna and Burrows, 2005; Chukwuka *et al.*, 2008).

India has a long history of flow regulation of rivers through dams and barrages for domestic water supply, flood control and irrigation (Gopal and Sah, 1993; Gopal, 2003; Shaw and Sutcliffe, 2003). Increasing population, rapid industrialization, agriculture expansion, changes in cropping patterns and land use patterns have increased the demand for water manifold resulting in overexploitation of both surface and ground water resources (Narula *et al.*, 2001; Gopal, 2003; Mall *et al.*, 2006; Smakhtin and Anputhas, 2006). Flow alteration, water pollution and increased silt loads have affected riverine biota drastically in many river basins resulting in decline in species diversity and a shift in species composition of various taxa (Chakrabarty and Chattopadhyay, 1989; Jhingran, 1991; Gopal, 2003).

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Yamuna basin covering about 11% of India's total land area (Gopal and Sah, 1993) has a number of industrial and agricultural centers. With an annual increase of 2.4% in human population since independence, more area is under irrigation reaching 110000 km^2 in the 1990s, up from 47000 km^2 during 1950s (from both surface and ground water resources) with more than 10000 large and medium and more than 1 million small scale industries presently working in the Yamuna basin (Narula *et al.*, 2001). Water abstraction from the river has increased many folds in last few decades with the decadal average flow in the river downstream of Hathnikund barrage (previously Tajewala) at Yamuna Nagar, Haryana reducing to around 3000 cumecs in 2000-2008 from over 15000 cumecs in 1961-70 (Panwar, 2009). The stretch of Yamuna from Wazirabad to Okhla, Delhi is barely 2% of the length of river, but contributes over 70% of the pollution load with high concentrations of heavy metal and residues of pesticides reported from this stretch (Rawat *et al.*, 2003; Aleem and Malik, 2005; CPCB, 2006). The wetland in Okhla Bird Sanctuary (OBS) has widest floodplains within this stretch and provides protection to the habitat because of its status. The present study highlights various hydrological characteristics of a man-modified floodplain wetland situated on Yamuna and floodplain vegetation associated with the wetland for effective conservation planning of the area.

MATERIALS AND METHODS

Study sites

India has a large network of rivers which has been forming foundation of human society since time immemorial with nearly all the major Indian cities located on the bank of one or the other river. They provide water for various uses including human consumption, irrigation, transportation, hydropower generation etc. Numerous perennial rivers originate from Himalaya, most of them falling either in the Indus Basin or Ganga - Brahmaputra Basin. The Yamuna river, one of the largest tributary of the River Ganga, originates from the Yamunotri glacier on the south western slopes of Banderpooch peaks in the state of Uttarakhand. It travels a total length of 1,376 km and has a drainage system of 366,233 km^2, about 42% of the Ganga river basin and about 11% of India's total land area (Gopal and Sah, 1993). Yamuna river basin covers 80 districts of seven states, partly covering Uttarakhand, Himachal Pradesh, Haryana, Uttar Pradesh, Madhya Pradesh and Rajasthan and covers entire state of Delhi. Narula *et al.* (2001) evaluated water sustainability indicators in Yamuna basin and found a large area to be under stressed conditions. The availability of renewable water (Falkenmark and Widstrand, 1992) was 1200 m^3 per capita while the use-to-resource ratio (Raskin *et al.,* 1996) was 34 %, thus putting the basin in stressed category. 20 out of 80 districts of the basin fell in highly stressed category based on population density, irrigation intensity, number of industrial facilities, surface water quality and flow etc. The Yamuna river enters Delhi at village Palla and leaves at Okhla, travelling a total distance of 48 km within Delhi. At Wazirabad, about 26 km after Palla, the river is trapped through a barrage for supplying drinking water to parts of Delhi. Water flow is very low downstream Wazirabad and the 22 km stretch of river from Wazirabad to Okhla mainly receives treated, partially treated or untreated domestic and industrial wastewater contributed by 22 drains beside canal water from Western Yamuna Canal (WYC) (through Najafgarh drain) and Upper Ganga Canal (UGC) (through Hindon Cut) (CPCB, 2006; Trisal *et al.*, 2008). High concentrations of heavy metals and residues of pesticides have been reported from this stretch of river (Rawat *et al.*, 2003; Aleem and Malik, 2005; CPCB, 2006; Trisal *et al.*, 2008), threatening flora and fauna of the river and associated habitats (Agarwal, 1997). At Okhla, water is again blocked and diverted into Agra Canal for irrigation through Okhla Barrage. Excessive anthropogenic pressure on the riparian habitat and high load of pollutants make this stretch of Yamuna the most threatened riverine habitat of the world (Kumar, 2001).

The OBS (Figure 1) is a man modified floodplain wetland situated within the NCR, Delhi and Biogeographic province 7A, Upper Gangetic plains (Rodgers and Panwar, 1988) of India. In the year 1990, the Government of Uttar Pradesh declared an area of 400 ha upstream Okhla Barrage that includes the main channel of River Yamuna, lake created due to construction of the barrage and various sand-bed islands within the river channel, a Bird Sanctuary. It is a freshwater ecosystem, performing important functions of a wetland amidst of metropolitan cities, providing significant ecosystem services in terms of groundwater recharge, erosion control, recreational values, educational values and aesthetic values. So far, a total of 87 fish species, 6 species of anurans, 28 species of reptiles and 30 species of mammals have been reported from OBS (WII, 2002). A total of 302 species of birds have been reported from several records since 1989 (Urfi, 2003) from the Sanctuary. The Sanctuary is recognized as an important bird area and a center for conservation education and recreation and it serves as a prominent wintering ground for water-birds with the presence of 13 globally threatened bird species (Urfi, 2003) (Urfi, 2006). Area has seen a reduction in wintering waterfowl numbers from over 25,000 in 1990-95 to less than 10,000 in 2005-06 with a significant change in abundance and community structure of birds (Urfi, 2006). The major sources of surface water entering the study area (inputs) include Yamuna (water released from the Wazirabad Barrage and municipal and industrial wastewater discharged into the river through a number of drains after Wazirabad) and Hindon river (water discharged from Hindon barrage), whereas major outflows include water released into Agra Canal for irrigational purposes and excess water released downstream (WII, 2002). Water level in the Sanctuary is maintained by the Okhla barrage which is controlled by irrigation department of Uttar Pradesh. The reservoir mainly contains sediments composed of the silt load carried by the Yamuna and Hindon river.

Methods

Hydrological characteristics

The data for water discharged downstream (into main river channel) from three barrages *viz.* Wazirabad, Yamuna and Okhla was collected from Delhi Jal Board and irrigation department of Uttar Pradesh. The data was used for flow patterns in various seasons from 2006 to 2010. GARMIN 160 C Fish Finder was used to estimate the depth of water. Echo-sounders use time lag between transmission and reception of the pulses after their reflection from bottom to give results (Barbosa *et al.*, 2006). The total study area was divided into 50 x 50 m^2 grids and water depth was recorded in each grid. The data were classified into four depth ranges viz., <1 m, 1.1 - 2 m, 2.1 – 3 m and >3 m. Water depth is one of the key parameters to characterize and understand a lot of processes in aquatic systems (Lehmann 1998; Tufford and McKellar, 1999; Gaytán *et al.*, 2008). Water quality analysis was done in summers of year 2009 and 2010. Grab water samples were collected in polyethylene bottles from the midstream (½ width of river) or from the well mixed zone from a depth of about 0.3 meters. In the year 2009, nine parameters (Table 2) were analyzed using standard methods for the analysis of water and waste water (APHA, 2005) while in the year 2010 onsite analysis was performed for selected parameters using HYDROLAB (a multi-parameter water quality instrument) and samples were preserved for rest. All field meters and equipment were checked and calibrated according to the manufacturer's specifications. Samples were preserved and brought to Wildlife Institute of India, Dehra Dun. In the year 2010, heavy metal analysis was carried out using flame atomic absorption spectrophotometer (ANALYSIS 700) that determines the chemical elements in a sample employing the absorption of optical radiation by free atoms in the gaseous state.

Vegetation characteristics

Sampling was done in open water and on the floodplains and on the islands present within river channel (Figure 1). Identification of plants in the field was made with the help of 'The Flora of Delhi' (Maheshwari, 1963). To calculate the coverage of open water by a submerged or free floating plant species, percent cover for the species was noted in 50 x 50 m^2 grids (same grids as used for bathymetry) and averaged for the total area. 1 x 1 m^2 plots were laid on the sand-beds (islands and floodplains) and vegetation was divided into upper stratum (mainly reeds) and lower stratum (various herbs). For the major species of upper stratum, data was collected to calculate Important Value Index (IVI) which was the summation of Relative frequency, Relative Biomass and Relative Cover. Above-ground biomass was harvested for upper stratum species from 1 x 1 m^2 plots. Fresh weight of samples were taken in the field and oven dried at 70°C till constant weight and then dry weight was also noted. As, in most of the plots contribution of lower stratum species in biomass was negligible, they were not harvested. However, one of the sand-bed islands had *Alternanthera* spp. and *Paspalum distichum* as dominant vegetation, their biomass was recorded. In both the habitats, plant cover was recorded by visual estimation. TWINSPAN (Two-way indicator species analysis) computer program (Hill, 1979) in PCORD 4 was used for classification of plant communities of sand-beds. Microsoft Excel was used for data management and the statistical analysis.

RESULTS

Hydrological characteristics

Water discharge from different barrages in Delhi: The water availability in Delhi stretch of Yamuna is regulated by three barrages *viz.* Wazirabad Barrage, Yamuna Barrage and Okhla Barrage. Wazirabad barrage impounds river to meet the need of water of Delhi and very little water is released downstream of the barrage. A comparison of water discharge from various barrages in different seasons (Figure 2) reveals that water discharge was zero from Wazirabad in the summers of years 2006 and 2010. There was no discharge from Wazirabad Barrage in the months of January, March - June and November in 2006, January 2007, January - May 2008, January - February, May June, October and December 2009, January - April 2010 despite declarations to maintain an environmentally sound flow in the river. Yamuna barrage is controlled by flood control department of Haryana. It is a water storage barrage and abstraction of water is done for Indraprastha power plant at Delhi. Water discharge from Wazirabad was always less than from Yamuna barrage except in the months of monsoon. As there is no source of freshwater between Wazirabad and Okhla barrages, this indicates the input of water into the stretch is primarily wastewater generated in the National Capital Territory, Delhi. The area is highly urbanized with high human population density, generating large volumes of wastewater which is ultimately discharged into the river. Water discharge was nil from Okhla barrage in the month of July in 2006. The barrage always had a minimum release of three cumecs into the river channel. Flow in the river was reduced considerably during winter and summer months. Year 2008 was a flood year in Delhi, resulting in discharge of large volumes of water downstream all barrages to avoid flooding.

Water depth profile of OBS wetland: During the year 2009-10, it was observed that maximum part of the wetland area is shallow. Water depth in 20% of the grids had depth below 1m and 45% of the grids had depth range between 1.1 - 2 m (Figures 3, Table 1). 20% area had depth between 2.1-3 m while for rest of the area (15%) water depth was more than 3 m. Water was deeper along the right marginal bund while shallower areas were found more along the left afflux bund road (Figure 3). This could be because of sedimentation in the area along left afflux bund as it is a lake and water is more stagnant in here. The area along the right marginal bund forms the river channel and thus has continuous flowing water. This gives an indication of the fact that the wetland might be facing threats of siltation. Owing to lack of relevant past data, the present work has set a baseline for future comparisons and monitoring.

Status of water quality: Data collected on the physical and chemical characters and nutrient contents have been presented in Tables 2 and 3. The average

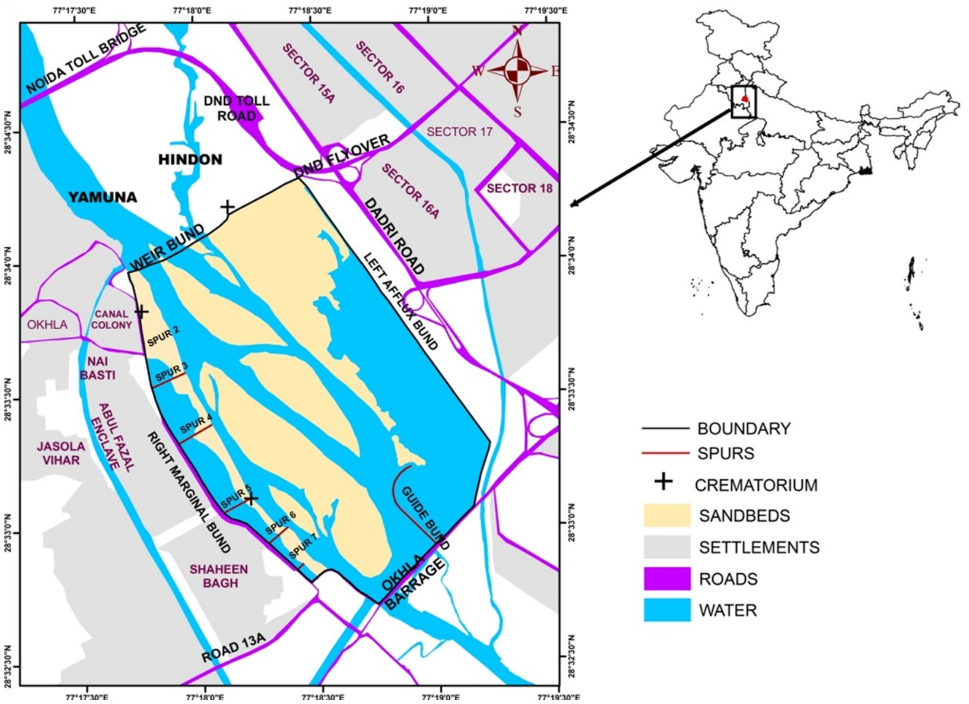

Figure 1. Map showing location of the Okhla Bird Sanctuary, National Capital Region, Delhi, India

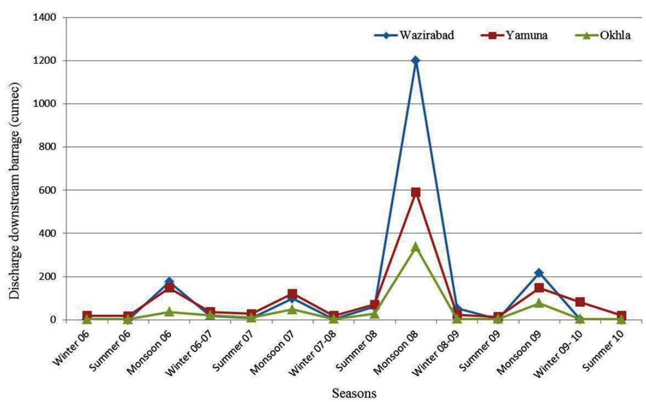

Figure 2. Graphical representation of water discharge from various barrages on Delhi stretch of Yamuna River, India.

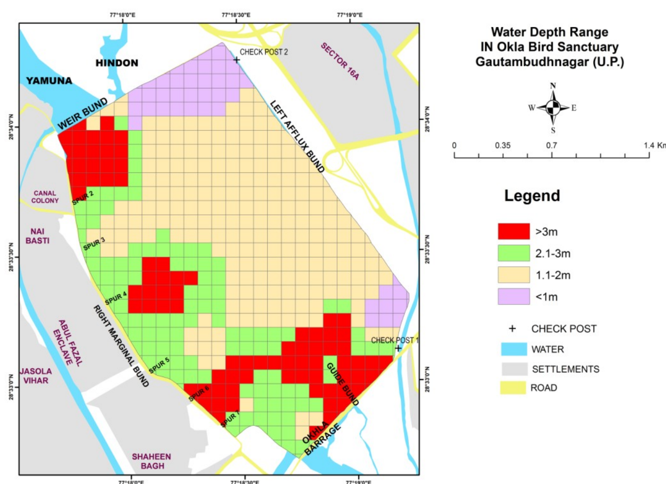

Figure 3. Map showing water depth characteristic of Okhla Bird Sanctuary, National Capital Region (NCR), Delhi.

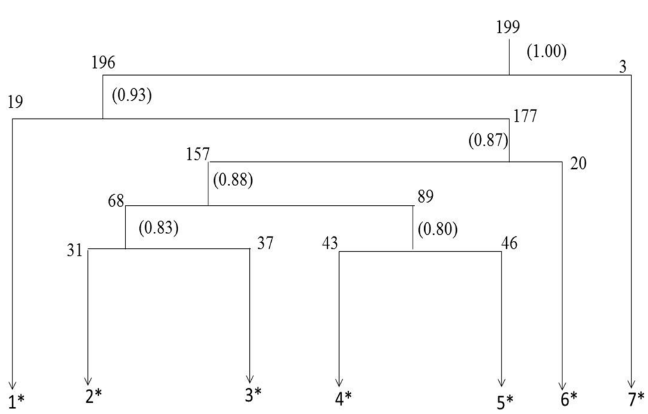

Figure 4. TWINSPAN classification of 199 plots (1 x 1 m^2 each) and 10 dominant emergent species into seven communities (values in parenthesis are eigenvalues) of the Okhla Bird Sanctuary, National Capital Region, Delhi, India.

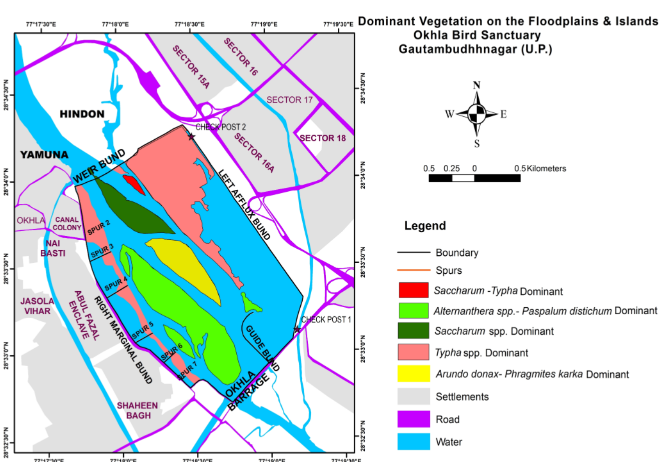

Figure 5. Map showing dominant vegetation of various sand beds in Okhla Bird Sanctuary, National Capital Region, Delhi, India.

temperature for the area was 27.67 ± 0.53 °C. Water in all the sites was alkaline with an average value of 8.45 ± 0.58, which touches the limit of 6.5 - 8.5 provided by Central Pollution Control Board of India (CPCB, 2006) for propagation of wildlife and fisheries in the river water. Average value for specific conductance was 1.56 ± 2.64 $mScm^{-1}$ while the turbidity had an average of 62.2 ± 14.28 % (NTU). All the sites (except one site in the year 2009) had dissolved oxygen (DO) value less than required limit of ≥4 mgl^{-1} or more given by CPCB (2008). The average value of DO for river water was 1.6 ± 0.84 mgl^{-1}. Sites with higher turbidity had lower DO values, which could be due to reduced intensity of light penetration into the water which might have decreased photosynthetic activities in the water. The biological oxygen demand (BOD) was 16.72 ± 4.28 mgl^{-1} and the average value of chemical oxygen demand (COD) for river water was 39.8 ±7.71 mgl^{-1}. The average values for various heavy metals were 0.102 ± 0.06 mgl^{-1} for cadmium, 0.016 ± 0.01 mgl^{-1} for chromium, 0.152 ± 0.02 mgl^{-1} for lead, 0.052 ± 0.05 mgl^{-1} for zinc, 0.002 ± 0.003 mgl^{-1} for copper, 34.163 ± 4.99 mgl^{-1} for calcium and 12.575 ± 1.77 mgl^{-1} for magnesium. The low value of DO and high values of BOD and COD indicate organic pollution in the water. The approximate COD and BOD ratio for untreated domestic sewage is >2 (Mara, 1978). In the present study, the COD/ BOD ration was higher than 2 (Table 2). This indicates presence of untreated sewage waste in the river water which needs biological treatment. Analysis for the heavy metals showed (Table 3) that concentrations of cadmium, chromium and lead were more than the permissible limits for water supporting aquatic life according to U.S. Environmental Protection Agency (1982), which is 0.012 mgl^{-1} for cadmium, 0.010 mgl^{-1} for chromium and 0.010 mgl^{-1} for lead. These metals enter into food chain by preferentially binding to particulate matters and are thus taken up by aquatic organisms, accumulating in them in large concentrations (Lorenz, 1979).

Vegetation characteristics

Eichhornia crassipes and *Typha angustifolia* were of major concerns impacting the floral communities of the Sanctuary. *E. crassipes* dominated open water habitat and was also present in the shallower areas. A native of tropical America, it has been classified as one of the worst aquatic weeds in the world (Global Invasive Species Database, 2010). It formed large floating mats over the water, alone or in association with other species which can be categorized as; pure hyacinth mats, mats of *E. crassipes* and *Alternanthera* spp. and free-floating mats of *E. crassipes* and *Salvinia auriculata* in the Sanctuary. *E. crassipes* formed continuous mats with *Alternanthera sessilis* and *A. philoxeroides* on bank (areas with fluctuating water depth) and in open water areas. All these communities covered almost 70% of open water habitat in the Sanctuary in summer of 2010. Overall 10 major species were recorded in the upper stratum of sand-beds (islands) for which above-ground biomass and IVI were calculated (Table 4). The dominant species was *Typha angustifolia* with an IVI value of 66 followed by *T. elephantina* (58.5), *Phragmites karka* (51) and *Arundo donax* (35.7). However, highest relative biomass was shown by *T. elephantina* (21.3) followed by *T. angustifolia* (20.2), *P. karka* (18.6) and *Arundo donax* (14.2). Average above-ground biomass for the area was 4.44 kg m^{-2} with highest above-ground biomass recorded for *A. donax* (4.84 kg m^{-2}) followed by *I. fistulosa* (4.57kg m^{-2}), *Saccharum spontaneum* (4.49 kg m^{-2}) and *P. karka* (4 kg m^{-2}).

Community classification: A total of 199 plots (each measuring 1 x 1 m^2) were sampled and analyzed for community classification. Resultant dendrogram from TWINSPAN is given in Figure 4 while different communities with dominant and associated species are given in Table 5. Seven broad communities have been recognized in the floodplains of OBS including sand-bed islands (Table 5). *P. karka* and *A. donax* community had most extent covering 23.6% of the studied plots. Associate species of this community were *T. angustifolia* and *T. elephantina* with *A. sessilis, A. philoxeroides, Chenopodium ambrosioides, Rorippa nasturtium-aquaticum* and *Cirsium arvense* present in lower stratum. Both the dominant species are highly resistant to floods and well established on one of the island in the middle of river flow. *T. elephantina* community had presence in 21.6% of the studied plots with *T. angustifolia* present as an associated species in some of the plots and *Cyperus kyllingia, Commelina benghalensis*, *Ranunculus sceleratus, and Rorippa nasturtium- aquaticum* present in lower stratum. It was present towards the dry area or areas with water depth of less than 0.5 m and was farther from the bank towards the center of the floodplains. However, plots with *T. angustifloia* were present towards the bank. These two communities along with *T. angustifolia* community (18.6% of studied area) and *Saccharum bengalense* community (15.6 % of studied area) covered more than 75% of total floodplains sampled. Associate and lower stratum species for *T. angustifolia* community were *T. elephantina, Dactyloctenium aegyptium* and *Polygonum hydropiper, P. barbatum, Ranunculus sceleratus, Cyperus bulbosus*, respectively while for *S. bengalense* community these were *T. angustifolia* and *C. ambrosioides, A. philoxeroides,, R. sceleratus, Cirsium arvense*, *Phyla nodiflora*, respectively. Other communities include *Alternanthera* spp. community (10% of studied area, *Paspalum distichum* as major associate species), *S. spontaneum* community (9.5% of studied area, *T. angustifolia* and *S. bengalense* as associate species and *R. sceleratus, R. nasturitium-aquaticum, P. distichum, Polygonum hydropiper* and *Phyla nodiflora* as lower stratum species) and *Ipomoea fistulosa- I. aquatica* community (1.5% of studied area and *Polygonum hydropipe* and *Cyperus kyllingia* as associate species).

DISCUSSION

The Yamuna river, Western Yamuna Canal, Upper Ganga Canal, Bhakara-Beas storage and ground water

Table 1. Water depth characteristics of Okhla Bird Sanctuary, NCR Delhi

Water Depth	Wetland area covered (%)
>1 m	20
1.1 - 2 m	45
2.1 - 3 m	20
>3 m	15

Table 2. Water quality parameters of Okhla Bird Sanctuary, NCR Delhi (Mean ± standard deviation)

Parameter	Mean ± SD
Temperature (°C)	27.67 ± 0.53
pH	8.45 ± 0.58
DO (mgl^{-1})	1.6 ± 0.84
BOD(mgl^{-1})	16.72 ± 4.28
COD (mgl^{-1})	39.8 ± 7.71
COD/BOD	2.52 ± 0.77
Specific conductance ($mScm^{-1}$)	1.56 ± 2.64
Salinity (PSS)	0.91 ± 1.28
Turbidity (NTU)%	62.17 ± 14.18

Table 3. Values for heavy metals in water of Okhla Bird Sanctuary, NCR Delhi (Mean ± standard deviation)

Parameter	Mean ± SD
Cadmium (mgl^{-1})	0.102 ± 0.06
Chromium (mgl^{-1})	0.016 ± 0.01
Lead (mgl^{-1})	0.152 ± 0.02
Zinc (mgl^{-1})	0.052 ± 0.05
Copper (mgl^{-1})	0.002 ± 0.003
Calcium (mgl^{-1})	34.164 ± 4.99
Magnesium (mgl^{-1})	12.575 ± 1.77

Table 4. Biomass and Importance Value Index of major plant species in upper stratum of floodplain vegetation in Okhla Bird Sanctuary, NCR Delhi

Species name	Biomass (kg m^{-2})	IVI
Typha angustifolia	2.78	66.0
Typha elephantina	3.84	58.5
Saccharum bangalensis	2.85	33.9
Saccharum spontaneum	4.49	27.0
Phragmite karka	4.00	51.0
Arundo donax	4.84	35.7
Paspalum distichum	0.61	4.1
Alternanthera spp.	1.17	18.9
Ipomoea fistulosa	4.57	4.2
Dactyloctenium aegyptium	1.10	0.6

Table 5. Plant communities of floodplains in Okhla Bird Sanctuary, NCR Delhi and their characteristics species based on TWINSPAN classification

Plant communities (# of plots)	Dominant Species	Associate species	Lower stratum species
1 (19)	*Saccharum spontaneum*	*Typha angustifolia, Saccharum bengalense*	*Ranunculus sceleratus*, *Rorippa nasturtium-aquaticum, Paspalum distichum, Polygonum hydropiper, Phyla nodiflora*
2 (31)	*Saccharum bengalense*	*Typha angustifolia*	*Chenopodium ambrosioides, Alternanthera philoxeroides, Ranunculus sceleratus, Cirsium arvense*, *Phyla nodiflora*
3 (37)	*Typha angustifolia*	*Typha elephantina, Dactyloctenium aegyptium*	*Polygonum hydropiper, P. barbatum, Ranunculus sceleratus, Cyperus bulbosus*
4 (43)	*Typha elephantina*	*Typha angustifolia*	*Cyperus kyllingia, Commelina benghalensis*, *Ranunculus sceleratus, Rorippa nasturtium-aquaticum*
5 (46)	*Phragmites karka* and *Arundo donax*	*Typha angustifolia, Typha elephantina,*	*Chenopodium ambrosioides, Rorippa nasturtium-aquaticum, Cirsium arvense*, *Alternanthera philoxeroides A. sessilis*
6 (20)	*Alternanthera* spp.	*Paspalum distichum*	*Cyperus compressus*, *Ipomoea fistulosa, Polygonum hydropiper*
7 (3)	*Ipomoea* fistulosa-*I. aquatica*	-	*Polygonum hydropiper, Cyperus kyllingia*

supply the raw water to entire Delhi of which around 63% of surface water requirements are fulfilled by Yamuna. Water is abstracted from Yamuna at Wazirabad barrage to meet demand of drinking water. Stretch of Yamuna in Delhi is highly braided and restricted between two lateral bunds after Wazirabad barrage. Three barrages regulate river flow, abstracting water for domestic use and irrigation while 22 drains discharge waste into the Yamuna within a stretch of only 22 km. There is no input of freshwater after Wazirabad into the river, however, Najafgarh drain and Hindon cut brings freshwater from WYC and UGC mixed with wastewater, respectively. The need to maintain a minimum flow with respect to ecological functions of the river has been realized by various concerned authorities and a couple of announcements have been made regarding this. In a MoU in the year 1994, various states falling in Yamuna basin agreed upon maintaining a minimum flow of 10 cumecs downstream of Tajewala (presently Hathnikund) and Okhla barrages throughout the year considering ecological requirements of riparian system, similarly, parliament made a declaration to provide a minimum flow of 10- 20 cumecs downstream both Wazirabad and Okhla barrages (Panwar, 2009). Despite these, discharge from Wazirabad was nil during the summers of 2006 and 2010. It was less than 10 cumecs from the same barrage in 7 seasons out of 14 seasons of study duration. 4 out of remaining 7 seasons were monsoon when water is released from all the barrages to avoid floods. Similarly, water discharge from Okhla Barrage was less than 10 cumecs in 8 seasons.

There are some indirect evidences of a decrease in water depth of Okhla barrage due to siltation, such as decline in the population of diving ducks and increase in the population of Greater Flamingo in the area (Urfi, 2006). The bird diversity is being affected by this as the deeper areas preferred by diving ducks like pochards (Ali and Ripley, 1987) are decreasing in the Sanctuary. The pochards accounted for about 9% of a sample of waterfowl population in OBS in 1989-95 but only 2 % in 2005-06 suggesting that the habitat is getting less hospitable for diving ducks (Urfi, 2006).

Degradation in water quality is directly affecting the biodiversity of the Sanctuary. Between Wazirabad to Okhla, 42.65 m^3sec^{-1} of wastewater is discharged into Yamuna (CPCB, 2006). The water quality in the Sanctuary is highly deteriorated reflected from low DO (1.6 ± 0.84 mgl^{-1}), high BOD (16.72 ± 4.28 mgl^{-1}) and COD (39.8 ± 7.71 mgl^{-1}) and heavy metals. Turbidity ($62.17 \pm 14.18\%$) is one of the indicators of impurities in water which could be organic in nature. Both Yamuna river and the Hindon Cut carry heavy silt load because of discharge of untreated and partially treated wastewater into them. Organic matter forms a large share of this discharge, besides being dumped into drains and river in the form of night soil from unauthorized colonies and religious offerings from time to time. The decomposition of this organic matter depletes dissolved oxygen of water and has affected biotic communities and self-purification capacity of the system. Okhla reservoir gives retention time to water and allows sediments (organic matter) to settle. This is supported by the point that Agra Canal, which is downstream to Okhla Barrage (Okhla Bird Sanctuary), had lower annual average of BOD and COD and higher DO levels than the levels at upstream of Okhla Barrage) (CPCB, 2006).

Water pollution especially during summer is believed to be one of the major issues that affect the integrity of the Sanctuary. However, creation of a reservoir, wide floodplains and addition of water from Hindon cut result in favorable conditions for the growth of vegetation belt which absorbs pollutants from water. Floodplains in the Sanctuary are subjected to various degree of flooding, continuous addition of wastewater, livestock grazing, and human induced fires. Each of the sand-bed islands was dominated by one or the other species of reed (Figure 5). High rates of sedimentation and addition of nutrients create conducive condition for plants like *Typha* spp., *P. karka* and *A. donax* which formed mono-specific or mixed stands in the area covering more than 60% of studied area. These species form climax communities in disturbed areas and cause competitive elimination of other species from the area (Tilton and Kadlec, 1979; Rieger and Kreager, 1989; Kumar *et al.*, 2011). *T. angustifolia, P. karka* and *A. donax* are tolerant to continuous inundation and a range of salinity and nutrients producing enormous amount of litter (Rieger and Kreager, 1989; Minchinton and Bertness, 2003; Koottatep, 2005) adding to the organic matter in the area. *T. angustifolia* was encountered most (32% plots) in the area followed by *T. elephantina* (24.6% plots), *P. karka* (20.6% plots) and *S. bangalense* (16.6% plots). *T. angustifolia*, a perennial macrophyte, is characterized by its fast growth, high biomass accumulation, and remarkable resistance to stress (Xu *et al.*, 2011). A study by Tabasum *et al.* (2009) reported *T. angustifloia* as the most common semi-aquatic species in the floodplains of Yamuna in Delhi with highest abundance recorded above Okhla barrage. *T. elephantina* flourishes in dry, upland and even saline zones by virtue of its deep-seated rhizomes (Chauhan and Gopal, 2005) thus was present farther from bank compared to *T. angustifolia.* Adaptation to a range of salinity, nutrient and hydrological conditions make both *P. karka* and *A. donax* efficient colonizer of human-modified or disturbed environment (Rieger and Kreager, 1989; Kumar *et al.*, 2011). *S. spontaneum* is commonly found on alluvial soils and can tolerate infrequent flooding and has good degree of drought tolerance (Dabadhagao and Shankarnayana, 1973; Skerman and Riveros, 1990). A large area of Yamuna floodplains in Delhi has been lost due to various development activities and rest is also under severe anthropogenic pressure. This, along with reduced river flow and polluted water has put immense pressure on floodplain vegetation. This may affect germination and growth of aquatic and semi-aquatic vegetation (Trisal *et al.*, 2005). The riparian zone is dynamic in nature due to its fluctuating hydrological regime that results in high biodiversity within the zone (Naiman *et al.*, 1993). This is reflected in OBS, where seven different plant communities have been found on different islands and shore area. Despite poor water quality and because of the presence of a wide floodplain that gives nutrients time to settle, area has higher coverage and higher diversity compared to rest of the river's stretch in Delhi.

CONCLUSION

The problem of heavy organic matter load in the Sanctuary is a result of broader watershed pollution along the Delhi stretch. The reduced flow, narrowing of floodplains due to restricted river channel and increased sedimentation as a result of dumping of untreated or partially treated wastewater into the river has degraded the system. Many areas in the Sanctuary have become monotypic stands of *Typha* spp., *P. karka* and *A. donax* and water is infested with mats of *E. crassipes.* Such monotypic stands alter the community composition impacting structural and hence functional aspects of the system (MacDonald *et al.*, 1989). The prime focus of various authorities responsible for conservation of Yamuna should not only be the allocation of water abstracted from the river basin but also the maintenance of an ecologically sound flow in the river/source. To improve water quality of the Sanctuary, steps should be taken to treat wastewater generated in the areas of National Capital Region, Delhi before discharging it into Yamuna and Hindon rivers. Industrial pollution should be controlled with thoughtful development of the residential and industrial areas. Treatment facilities should be strengthened in the NCR. The floodplains of Yamuna should be treated as ecologically sensitive areas thus should be given due importance in city planning.

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REFERENCES

Agarwal A. (ed.). 1997. *Homicide by Pesticides: What Pollution does to our Bodies*. New Delhi: Centre for Science and Environment, State of the Environment Series 4.

Alcantara E, Novo E, Stech J, Assireu A, Nascimento R, Lorenzzetti J, Souza A. 2009. Integrating historical topographic maps and SRTM data to derive the bathymetry of a tropical reservoir.http://mtc-m18.sid.inpe.br/col/sid.inpe.br/mtc-m18%4080/2009/09.30.22.11/doc/v1.pdf (Retrieved on 11th May 2012)

Aleem A, Malik A. 2005. Genotoxicity of the Yamuna River water at Okhla (Delhi), India. *Ecotoxicology and Environment Safety* 61: 404–412. DOI:10.1016/j.ecoenv.2004.09.001.

Ali S, Ripley SD. 1972. Handbook of the Birds of India and Pakistan, Vol. 1-9. Oxford University Press, Bombay, India, 2667 p

Barbosa CCF, Novo EMLM, Melack JM, Freitas RM, Filho WP. 2006. A methodology for analysis of volume and flooded area dynamics: Logo Grande de Curuai varzea as an example. *Revista Brasileira de Cartografia* 58: 201-210.

Barko JW, Smart RM. 1983. Effects of organic matter additions to sediment on the growth of aquatic plants. *The journal of Ecology* 71: 161-175. 0022-0477/83/0300-0161$02.00.

Barko JW, Adams MS, Clesceri NL. 1986. Environmental factors and their consideration in the management of submersed aquatic vegetation: A review. *Journal of Aquatic Plant Management* 24: 1-10.

Bugenyi FWB, Balirwa JS. 1998. East African Species Introduction of Wetland management: Socio-political dimensions. Emerging Water Management Issues. *AAAS Africa Program Symposium Proceedings.* http://www.aaas.org/international/africa/ewmi/bugenyi.htm (Retrieved on 1st March 2012).

Buijse AD, Coops H, Staras M, Jans LH, Van Geest GJ, Grifts RE, Ibelings BW, Oosterberg W, Roozen CJM. 2002. Restoration strategies for river floodplains along large lowland rivers in Europe. *Freshwater Biology* 47: 889-907.

Central Pollution Control Board (CPCB). 2006. *Water quality status of Yamuna River (1999 – 2005)*. Assessment and Development of River Basin Series: ADSORBS/41/2006-07. http://www.cpcb.nic.in/newitems/11.pdf (Retrieved on 25th January 2012).

Central Pollution Control Board (CPCB). 2008. Guidelines for water quality monitoring. New Delhi. MINARS/27/2007-08 (Retrieved on 25th February 2012).

Chakraborty PK, Chattopadhyay GN. 1989. Impact of Farakka barrage on the estuarine ecology of the Hooghly-Matlah system. In Jhingran AG, Sugunan VV. (eds). *Conservation and management of inland capture fisheries resources of India*. Barrackpore, Inland Fisheries Society of India.

Chauhan M, Gopal B. 2005. Vegetation structure and dynamics of a floodplain wetland along a subtropical regulated river. *River Research and Application* 21: 513-534.

Chukwuka KS, Uka UN, Omotayo OE. 2008. Influence of persistent presence of water hyacinth on specific physicochemical properties of a freshwater body in Southwestern Nigeria. *Zonas Áridas* 12: 209-217.

Dabadhagao PM, Shankarnarayana KA. 1973. *The Grass Cover of India*. Indian Council of Agricultural Research, New Delhi, India.

de Winton MD, Clayton JS. 1996. The impact of invasive submerged weed species on seed banks in lake sediments. *Aquatic Botany* 53: 31-45.

Dudgeon D. 2000. Large-scale hydrological changes in Tropical Asia: Prospects for riverine biodiversity. *Bio Science* 50: 793-806.

Falkenmark M, Widstrand C. 1992. Population and water resources: a delicate balance. *Population Bulletin* 47: 1-36.

Gaytán R, De Anda J, Nelson J. 2008. Computation of changes in the run-off regimen of the lake Santa Ana watershed (Zacatecas, Mexico). *Lakes and Reservoirs: Research and Mangement* 13: 155-167. DOI: 10.1111/j. 1440-1770.2008. 00364.x

Gichuki J, Reuben O, Tom O, Matano A, Boera P, Jembe T, Ofulla A. 2009. Water hyacinth *Eichhornia crassipes* (Mart.) Solms – Laubach dynamics and Succession in the Nyanza Gulf of Lake Victoria (East Africa): Implications for Water Quality and Biodiversity Conservation. *13th World Lakes Conference*. November 1-5 2009. Wuhan, China.

Global Invasive Species Database. 2010. *Eichhornia crassipes* (aquatic plant). Electronic database at http://www.issg.org/database/species/ecology.asp?si=70&fr=1&sts=sss&lang=EN (Retrieved on 19th January 2012).

Gopal B. 2003. State of degradation and approaches to restoration of floodplain rivers in India. The Second International Symposium on *the Management of Large Rivers for Fisheries: Sustaining livelihood and biodiversity in the new millennium*. 11th-14th February 2003. Phnom Penh, Kingdom of Cambodia.

Gopal B, Sah M. 1993. Conservation and Management of Rivers in India: Case-study of the River Yamuna. *Environmental Conservation* 20: 243-254.

Hill MO. 1979. TWINSPAN. A Fortran program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Cornell University, Ithaca, New York.

Hudon C. 2004. Shift in wetland plant composition and biomass following low-level episodes in the St. Lawrence River: looking into the future. *Canadian journal of Aquatic Sciences* 61: 603-617.

James CS, Fisher J, Russell V, Collings S, Moss B. 2005. Nitrate availability and hydrophyte species richness in shallow lakes. *Freshwater Biology* 50: 1049-1063.

Jhingran VG. 1991. *Fish and fisheries of India* (Third Edition). Hindustan Publishing Corporation: New Delhi.

Junk WJ, Bayley PB, Sparks RE. 1989. The flood pulse concept in river floodplain systems. Special publication- *Canadian Journal of Fisheries and Aquatic Sciences* 106: 110-127.

King J, Brown A, Sabet H. 2003. A scenario-based holistic approach to environment flow assessments for rivers. *River Research and Application* 19: 619 -639.

Koottatep T, Surinkul N, Polprasert C, Kamal ASM, Kone D, Montangero A, Heinss, U, Strauss M, 2005. Treatment of septage in constructed wetlands in tropical climate: lessons learnt from seven years of operation. *Water Science and Technology*. 51: 119–126.

Kumar P. 2001. Cost of wetland conversion: A case study of floodplain wetland ecosystems along the Yamuna river corridors of Delhi region. Open meeting of the *Global Environmental Change Research Community,* 6th-8th October 2001, Rio de Janeiro: Brazil.

Kumar R, Pattnaik A, Pattnaik P. 2011. Management of *Phragmites karka* invasion in Chilika Lake, Orissa. Consultation workshop on Management of *Phragmites karka* invasion in Chilika, 17th-18th January 2011, Bhubaneswar, Orissa.

Lehmann A. 1998. GIS modeling of submerged macrophyte distribution using Generalized Additive Models. *Plant Ecology* 139: 113-124.

Lorenz EN. 1979. Forced and free variations of weather and climate. *Journal of the Atmospheric Sciences* 36:1367-1376.

Lougheed VL, Crosbie B, Fraser CP. 2001. Primary determinants of macrophyte community structure in 62 marshes across the Great Lakes basin: latitude, land use, and water quality effects. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 1603-1612.

Lytle DA, Merritt DM. 2004. Hydrologic regimes and riparian forests: a structured population model for Cottonwood. *Ecology* 85: 2493- 2503

Macan TT. 1977. The influence of predation on the composition of fresh-water animal communities. *Biological Reviews* 52: 45–70.

MacDonald IA, Loope LL, Usher MB, Hamann O. 1989. Wildlife conservation and the invasion of nature reserves by introduced species: a global perspective. *Wetlands* 22: 451–466.

Maheshwari JK. 1963. *The Flora of Delhi*. Council of scientific and Industrial Research: New Delhi, India.

Mall RK, Gupta A, Singh R, Singh RS, Rathore LS. 2006. Water resources and climate change: An Indian perspective. *Current Science* 90: 1610-1626.

Mara D. 1978. Sewage treatment in hot climates. John Wiley and Sons: Chichester, UK.

Minchinton TE, Bertness MD. 2003. Disturbance-Mediated Competition and the Spread of *Phragmites australis* in a Coastal Marsh. *Ecological Applications* 13: 1400-1416.

Misra RD. 1938. Edaphic factors in the distribution of aquatic plants in the English lakes. *Journal of Ecology* 26: 411-451.

Naiman RJ, Decamps H, Pollock M. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3: 209–212.

Narula KK, Wendland F, Bhujanga R, Bansal NK. 2001. Warer resources development in the Yamuna river basin in India. *Journal of Environmental Studies and Policy* 4: 21-33.

Nilsson C, Grelsson G, Johansson M, Sperens U. 1989. Patterns of plant species richness along river banks. *Ecology* 70: 77–84.

Panwar HS. 2009. *Reviving river Yamuna: An actionable blue print for a blue river.* PEACE Institute Charitable Trust: Delhi.

Pearsall WH. 1920. The Aquatic Vegetation of the English Lakes. *Journal of Ecology* 8:163 201.

Perna C, Burrows D. 2005. Improved dissolved oxygen status following removal of exotic weed mats in important fish habitat lagoons of the tropical

Budrekin river floodplain, Australia. *Marine Pollution Bulletin* 51: 138-148.

Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC. 1997. The natural flow regime: a paradigm for river conservation and restoration. *BioScience*. 47: 769-784.

Raskin P, Hansen E, Margolis R. 1996. Water and sustainability: global patterns and long range problems. *Natural Resource Forum* 20: 1-16.

Rawat M, Moturi MCZ, Subramanian V. 2003. Inventory compilation and distribution of heavy metals in wastewater from small-scale industrial areas of Delhi, India. *Journal of Environment Monitoring* 5: 906-912.

Rieger JP, Kreager DA. 1989. *Giant reed (Arundo donax) : a climax community of the riparian zone*. USDA Forest Service General Technical Report: PSW- 110.

Rodgers WA, Panwar HS. 1988. *Planning a protected area network in India.* Vol. I- The report. Wildlife Institute of India: Dehra Dun.

Shaw J, Sutcliffe J. 2003. Ancient dams, settlement archaeology and Buddhist propagation in central India: the hydrological background. *Hydrological Sciences* 48: 277-291.

Skerman PJ, Riveros F. 1990. *Tropical Grasses*. FAO Plant Production and Protection Series No. 23. Food and Agriculture Organization of the United Nations. Scientific Publishers: Jodhpur.

Smakhtin V, Anputhas M. 2006. An assessment of environmental flow requirements of Indian River Basins. Colombo, Sri Lanka: International Water Management Institute. IWMI Research Report 107. 1SSN 1026-0862.6

Stromberg JC, Fry J, Patten DT. 1997. Marsh development after large floods in an alluvial, arid-land river. *Wetlnads* 17: 292-300.

Stromberg, J. C., Beauchamp, V. B., Dixon, M. D., Lite, S. J. and Paradzick, C. 2007. "Importance of low-flow and high-flow characteristics to restoration of riparian vegetation along rivers in arid south-western United States." *Freshwater Biology,* 52 (4): 651-679

Tabasum T, Bhat P, Kumar R, Fatma T, Trisal CL. 2009. Vegetation of the river Yamuna floodplain in the Delhi stretch, with reference to hydrological characteristics. *Ecohydrology* 2: 156-163. DOI: 10.1002/eco

Tamot S, Sharma P. 2006. Physico-chemical status of Upper Lake (Bhopal, India): water quality with special reference to Phosphate and Nitrate concentration and their impact on Lake ecosystem. *Asian Journal of Experimental Sciences* 20: 151-158.

Tharme RE. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Application* 19: 397-441. DOI: 10.1002/rra.736.

Titlon DL, Kadlec RA. 1979. The utilization of a fresh water wetland for nutrient removal from secondarily treated wastewater effluent. *Journal of Environmental Quality* 8: 328-334.

Trisal CL, Bhat P, Tabasum T, Ray J, Vishwakarma M. 2005. Ecological assessment of river Yamuna floodplains in Delhi stretch with emphasis on changes in biodiversity. In *Proceedings of a Conference on Asian Wetland Symposium.* 6th- 9th February 2005. Bhubaneswar, Orissa : India.

Trisal C, Tabassum T, Kumar R. 2008. Water quality of the river Yamuna in the Delhi stretch: key determinants and management issues. *Clean* 36: 306-314.

Tufford DL, McKellar HN. 1999. Spatial and temporal hydrodynamic and water quality modeling analysis of a large reservoir on the South Carolina (USA) coastal plain. *Ecological Modeling* 114: 137-173.

Urfi AJ. 2003. The birds of Okhla Bird Sanctuary, Delhi, India. *Forktail* 19: 39-50.

Urfi A J. 2006. Biodiversity conservation in an urban landscape: a case study of some important bird areas on the river Yamuna in Delhi (India). *Conservation Biology in Asia*. McNeely JA, McCarthy TM, Smith A, Olsvig- Whittaker L, Wikramanayake ED (eds). The Society for Conservation Biology Asia Section and Resources Himalaya, Kathmandu: Nepal.

U.S. Environmental Protection Agency. 1982. Maximum contaminant levels (subpart B of part 141, National interim primary water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149: 315-318.

WII. 2002. *Ecological, social and hydrological factors affecting the management of wetland systems in Uttar Pradesh with special reference to Vijay Sagar and associated water bodies in Mahoba district, Okhla and associated water bodies in Ghaziabad district, Bakhira Bird Sanctuary, and Nawabganj Bird Sanctuary*. Wildlife Institute of India, Dehra Dun.

Xu, J., C. Li, F. Yang, Z. Dong, J. Zhang, Y. Zhao, P. Qi and Z. Hu. 2011. *Typha angustifolia* stress tolerance to wastewater with different levels of chemical oxygen demand. *Desalination* 280: 58-62.