REJUVENATION OF URBAN LAKES IN DRY TROPICS: PROBLEMS AND PERSPECTIVES

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INTRODUCTION

For more than three decades, inland water bodies are subjected to increasingly high human pressure through direct discharge and through changes in land-use by forest thinning, grazing, cultivation and excavation for mineral extraction (Rhazi *et al.*, 2001). In tropics where light and temperature are generally optimal, nutrient status becomes the major determinant of aquatic ecosystem properties (Wetzel, 2001). Terrestrial systems contribute to surface waters by adding nutrients through run-off. The nature of such addition depends on catchment characteristics, land-use pattern, human modifications and atmospheric depositions (Nagakwa and Iwatsubo, 1999; Rhazi *et al.*, 2001; Pandey and Yaduvanshi, 2003). Such additions not only regulate water chemistry and biology but also effects microbial biomass dynamics at land-water interface which in turn, regulates nutrient pulsation in lake water and consequently phytoplankton bloom (Pandey and Pandey, 2001)

Not all the nutrients that nourish aquatic ecosystems are derived from terrestrial catchments, atmospheric depositions through aerial catchment also contribute to the process. (Lepisto *et al.*, 1995). In addition to the direct depositions onto the water surfaces, terrestrial catchments also serve as receptors of aerially derived materials, part of which is reexported through run-off to downstream water bodies (Kalff, 2002). Since the nutrient loading through run-off vary depending upon surface features, atmospheric deposition and catchment modifications, it is important to quantify the magnitude of spatial variations in nutrient loading as modified by anthropogenic perturbations. Despite the role of external nutrient loading in surface water quality, internal flushing of nutrient from sediments also play important role regulating ecosystem properties specially in shallow lakes (Beklioglue, 1999; Søndergaard *et al.,* 2000). Recovery resilience following reduction in external nutrient loading is a major constraint in restoration practices of shallow lakes due to internal flushing of nutrients. Recent efforts have suggested sediment dredging as an effective tool reducing internal flushing of nutrients specially P and thereby reversing the trophic status towards oligotrophy. (Jeppesen *et al.*, 1991; Søndergaard *et al.*, 2000; Kingston and Ramadas, 2005). The present study was an effort to quantify the role of atmospheric deposition and catchment run-off in regulating water chemistry and biology of three freshwater lakes of southern Rajasthan and exploring possibilities of their rejuvenation.

MATERIALS AND METHODS

The study was conduced during January 2002 to December 2004 at three freshwater lakes of Udaipur .The lakes, Fatehsagar, Udaisagar and Baghdara, differ with respect to the catchment characteristics and the magnitude of anthropogenic perturbations. Lake Fatehsagar (24° 35′ N lat and 73° 37′ E long ; 578 m above msl; catchment 5400 ha; surface area 4 km^2, maximum depth 13.4 m) receive nutrients partly from urban wash and partly from forested catchment. Lake Baghdara (24° 31′ N lat. and 73° 48′ E long and 577 m above msl; catchment 500 ha; surface area 1.8 km^2; maximum depth 8.5m) which is situated about 20 km SE of Udaipur city in the midst of a deciduous forest is subjected to least human interference. However, this lake is receiving atmospheric deposition from phosphate fertilizer factories from a few years. Lake Udaisagar (24° 35′ N lat, 73°48′ E long and 542 above msl; catchment 2600 ha; surface area 7.7 km^2; maximum depth 11.2 m) which is situated about 14 km SE of Udaipur city receive inputs from anthropogenic discharge and from catchment modifications.

Climate of the region is characterized by a short monsoon season and an extended period of dryness. The mean annual precipitation during the study period were 498, 597 and 567 mm for the year 2002, 2003 and 2004 respectively. Mean monthly temperature some times exceeds 40°C during summer. Winter temperature some time drops below freezing.

Wet depositions were collected during monsoon and dry depositions were collected seasonally for three consecutive years (2002-2004). Wet and dry depositions thus collected were analyzed for total-N and total-P following standard methods. The run-off waters in triplicate were collected along the topographical gradients from all the catchment categories during monsoon for three successive hydrological cycles. The properties such as dissolved organic-C (DOC), nitrate-N and phosphate-P in run-off waters were determined following standard methods (APHA, 1998). Sediment samples were collected by using 2.5 cm diameter PVC tubes (5-10 cm long cores; 8 m reach) and analyzed for organic-C (Page *et al.*, 1982), total-N and total-P (Jackson, 1973). During dry periods, vast quantity of bottom sediment was removed by local people from Fatehsagar and Udaisagar. The amount of sediment removed was measured using volume-density relationship (Miller and Donaue, 1992). Water samples in triplicate were collected from all the lakes at monthly intervals and dissolved organic-C (DOC), nitrate-N, phosphate-P were determined following standard methods (APHA, 1998). Gross primary productiviy (GPP) was measured using light and dark bottle method (Wetzel and Likens, 1979). Humus samples were collected from land-water interface of three lakes and analyzed for microbial biomass-C (C_{mic}) following Jenkinson and Powlson (1976) as modified by wardle *et al.*(1993).

The results obtained for chemical and biological characteristics of lake water were analyzed using two-way analysis of variance.

RESULTS AND DISCUSSION

Data on atmospheric deposition of N and P were presented in Table1. Wet and dry depositions of P were maximum at Baghdara and that of N were maximum at Udaisagar. Atmospheric deposition of these elements increased gradually from the year 2002 to 2004. Although there exist considerable variations, atmospheric depositions increase nutrient flushing in terrestrial and aquatic ecosystems (Singh and Tripathi, 2000). Industrial emission and agricultural soils raise atmospheric N and P significantly (Brezonik, 1996). Total-N in precipitation could range from about 100 kg km^{-2} yr^{-1} in remote areas to 2000 kg km^{-2} yr^{-1} in industrial and agricultural regions (Kalff, 2002). This effect was evident in the present study for

Table 1: Atmospheric deposition of N and P at three lake sites of Udaipur. Values are mean ± 1 SD.

Variable	Fatehsagar			Udaisagar			Baghdara		
	2002	2003	2004	2002	2003	2004	2002	2003	2004
DOC ($mg\ L^{-1}$)	4.19 ± 0.39	4.26 ± 0.37	4.39 ± 0.31	6.13 ± 0.62	6.51 ± 0.71	6.98 ± 0.75	6.84 ± 0.45	7.12 ± 0.51	7.29 ± 0.55
NO_3-N ($\mu g\ L^{-1}$)	57.4 ± 8.28	60.6 ± 7.14	63.9 ± 9.98	78.4 ± 8.08	82.97 ±10.07	86.11 ± 8.91	41.78 ± 6.98	44.54 ± 5.91	49.81 ± 6.99
PO_4-P ($\mu g\ L^{-1}$)	24.82 ± 4.41	26.71 ± 3.35	29.74 ± 4.36	31.21 ± 4.88	33.24 ± 3.72	35.41 ± 4.95	27.22 ± 3.09	29.91 ± 3.12	31.43 ± 3.12

Udaisagar characterized by vast stretch of agricultural land and for Baghdara situated downwind of phosphate fertilizer factories. Atmospheric N and P delivered directly onto the upper water surfaces, where light availability promote rapid uptake into photosynthetic organisms, could accelerate eutrophication in oligotrophic monomictic lakes situated even in remote areas (Sigee, 2005). Run-off water chemistry varied with the nature of lake catchment and the extent of human modifications. The influence of atmospheric deposition was also evident in run-off water quality. Run-off water from catchments of Udaisagar contained high concentration of nitrate-N and phosphate-P. Dissolved organic carbon in run-off was maximum for lake Baghdara characterized by forested catchment (Table 2).

Table 2: Run-off water chemistry of catchments of Fatehsagar, Udaisagar and Baghdara lakes of Udaipur. Values are mean ± 1 SD.

Variable	Fatehsagar			Udaisagar			Baghdara		
	2002	2003	2004	2002	2003	2004	2002	2003	2004
Dry Deposition ($kg\ ha^{-1}\ a^{-1}$)									
Total-N	8.15 ± 0.94	9.01 ± 0.98	9.94 ± 0.92	14.87 ± 1.04	15.45 ± 1.60	16.93 ± 1.97	5.75 ± 0.61	5.86 ± 0.71	5.98 ± 0.71
Total-P	0.71 ± 0.66	0.74 ±0.96	0.78 ± 0.68	0.85 ± 0.98	0.86 ± 0.87	0.87 ± 0.89	0.86 ± 0.08	0.98 ± 0.09	1.08 ± 0.14
Wet Deposition ($kg\ ha^{-1}\ a^{-1}$)									
Total-N	13.26 ± 1.31	14.00 ± 1.59	14.85 ± 1.14	i9.77 ± 1.98	20.12 ± 1.46	20.97 ± 2.27	9.24 ± 1.20	9.45 ± 0.95	9.52 ± 1.30
Total-P	1.92 ± 0.21	1.93 ± 0.24	1.95 ± 0.19	2.60 ± 0.31	2.67 ± 0.41	2.74 ± 0.37	2.69 ± 0.31	2.88 ± 0.40	3.25 ± 0.44

Nutrient concentrations in run-off water increased during successive years indicating increased human emission. Lake Udaisagar also receives up to 0.089 mg L^{-1} of nitrate-N, 0.032 mg L^{-1} of phosphate-P and 5.74 mg L^{-1} of dissolved organic carbon through streamflow (Table 3). Microbial biomass (C_{mic}) was high at lake Udaisagar characterized by extensive agricultural activity in its catchment. The effects of agricultural residues relative to those of tree foliage in lake Baghdara is because agricultural residues are more easily decomposable and have higher nutrient contents than do the tree foliage (Wardle *et al.*, 1999).

Table 3: Streamflow concentrations of N, P and DOC ending to lake Udaisagar

Variable	Year		
	2002	2003	2004
NO_3-N (mg L^{-1})	0.055 ± 0.007	0.077 ± 0.008	0.089 ± 0.01
PO_4-P (mg L^{-1})	0.030 ± 0.004	0.031 ± 0.004	0.032 ± 0.004
DOC (mg L^{-1})	5.54 ± 0.60	5.68 ± 0.67	5.74 ± 0.71

Despite continued addition through streamflow (Udaisagar), catchment run-off and atmospheric deposition, nutrient levels in Udaisagar and Fatehsagar dropped significantly during successive years. This could be attributed to sediment removal reducing internal flushing of nutrients (Søndergaard *et al.*, 2000). About 2147.1 tons of sediment containing 387.57 kg of N, 287.37 kg of P and 21160.46 kg of C was removed from lake Fatehsagar during three dry phases (Table 4). For Udaisagar, removal of nutrients along with sediments was significantly higher. The effect of sediment removal was also reflected through lowered primary productivity (Fig. 1). Two-way analysis of variance indicated significant spatio-temporal variations in water chemistry and productivity variables. Nutrient concentrations and productivity of Baghdara lake which did not suffer sediment removal, increased with time. Declining trends in nutrient and trophic status following bottom sediment removal could be considered as recovery towards oligotrophy.

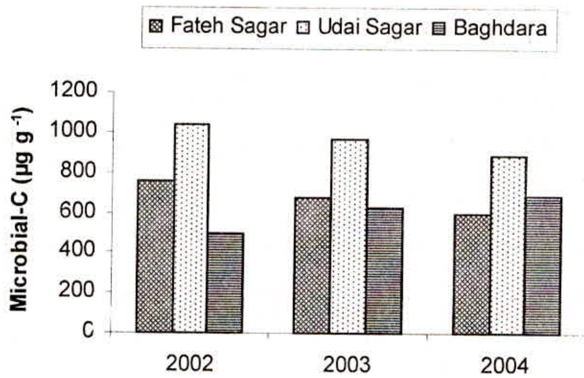

Figure 1: Microbial biomass- C (µg g^{-1}) in humus collected from land-water interface of three lakes of Udaipur.

Table 4: Bottom sediment (tons) and nutrient removal from two lakes of Udaipur. (Values in parenthesis are coefficient of variation)

Lake	Parameter	Dry Periods						Total
		May – June 2001		May – June 2002		April – June 2003		
Fatehsagar	Sediment	730.80	(0.18)	855.40	(0.13)	560.90	(0.21)	2147.10
	Total-N	146.16	(0.11)	150.55	(0.10)	90.86	(0.13)	387.57
	Total –P	109.62	(0.15)	99.23	(0.16)	78.52	(0.13)	287.37
	Organic-C	8915.76	(0.18)	7869.68	(0.16)	4375.02	(0.16)	21160.46
Udaisagar	Sediment	1050.0	(0.22)	1730.0	(0.18)	1425.60	(0.19)	4205.60
	Total-N	285.60	(0.14)	423.85	(0.11)	327.89	(0.12)	1037.34
	Total –P	177.45	(0.16)	230.09	(0.13)	168.22	(0.18)	575.76
	Organic-C	14595.42	(0.19)	19030.04	(0.21)	13543.20	(0.16)	47168.20

Table 5: Chemical characteristics of water samples collected from three lakes of Udaipur. Values are mean ± 1 SD.

Variable	Fatehsagar			Udaisagar			Baghdara		
	2002	2003	2004	2002	2003	2004	2002	2003	2004
DOC ($mg\ L^{-1}$)	3.11 ±0.27	2.80 ±0.29	2.41 ±0.31	3.53 ±0.29	3.07 ±0.44	2.76 ±0.31	3.46 ±0.34	3.92 ±0.38	4.30 ±0.46
NO_3-N ($\mu g\ L^{-1}$)	321.51 ±29.46	269.51 ±27.71	207.51 ±22.99	743.01 ±85.12	640.51 ±82.44	523.41 ±58.87	126.40 ±14.78	190.65 ±18.19	212.47 ±24.55
PO_4-P ($\mu g\ L^{-1}$)	108.87 ±8.58	102.05 ±12.89	95.32 ±10.12	175.64 ±16.51	167.82 ±16.99	154.83 ±18.87	85.81 ±9.97	96.28 ±9.81	107.93 ±12.03

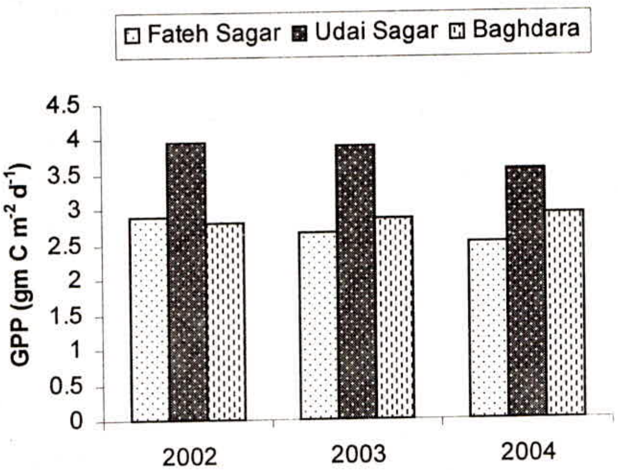

Figure 2: Gross primary productivity (GPP) of the water samples collected from three lakes of Udaipur.

Table 6: 'F' ratios obtained from two-way analysis of variance (ANOVA) for water chemistry and productivity variables

Variable	L	Y	L x Y
DOC	14.76**	11.76**	6.05**
NO_3-N	96.21**	39.48**	31.27**
PO_4-P	66.28**	26.48**	14.06**
GPP	84.92**	268.20**	118.72**

L = lakes; Y = year; L x Y = interactions

* F ratios significant at 5 %; **significant at 1 %; NS: not significant

The study suggests that the direct anthropogenic discharge, disruption of land-use pattern in the catchment along with atmospheric deposition severely affects lake ecosystem structure and functioning. The study also suggests that the sediment dredging could be used as an effective tool towards restoration of shallow tropical lakes. This has relevance in dry regions where scanty rainfall frequently exposes the lake bottom during summer.

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