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Variations in physical and chemical parameters and plankton community structure in a series of sewage-stabilization ponds

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Abstract: Variations in physical and chemical parameters and plankton community structure from urban-based sewage stabilization ponds in Delhi (India) were recorded from summer to winter months of 1992-1993. The quantified physico-chemical variables were temperature, pH, dissolved oxygen, soluble reactive phosphorus, total phosphorus, nitrate-nitrogen and chlorophyll-*a*. A qualitative analysis of the phytoplankton in all the ponds was made. Among zooplankton, rotifers, cladocerans, and copepods were identified and quantified. Observations were taken every month concentrations of soluble reactive phosphorus, total phosphorus and nitrate-nitrogen ranged between 1.2-2.0 mg l^{-1}, 2.0-3.5 mg l^{-1}, and 0.075-0.30 mg l^{-1}, respectively. Although there were no significant differences in the nutrient concentrations between any of the ponds, the ponds receiving the raw sewage first had undetectable levels of chlorophyll-*a* for a greater part of the sampling period. As the water passed through the series of ponds, the quality improved and finally supported high zooplankton densities. There were summer blooms of *Euglena, Pandorina, Spirulina* and *Oscillatoria*. The commonly found rotifer species were *Brachionus calyciflorus*, *Hexarthra mira* and *Filinia longiseta*. Cladocera and Copepoda were represented, almost exclusively, by *Moina macrocopa* and *Mesocyclops thermocyclopoides* respectively.

Keywords: Phytoplankton, zooplankton, nutrients, sedimentation ponds

All natural water bodies experience the process of eutrophication with time. However, human activities such as agriculture and domestic sewage production can greatly enhance this process, especially if untreated waste water is allowed to flow into lakes and rivers. While in most waterbodies, the hypereutrophic state is undesirable, certain man-made aquatic systems such as intensive culture fish ponds and sewage treatment ponds are intentionally hypereutrophic (Uhlmann 1980). Input of tr ated water from the latter into other reservoirs, rather than raw sewage, prevents them from becoming eutrophic.

As raw domestic sewage passes through a series of stabilization ponds, there is a settlement of wastes into sludge which is effectively decomposed by bacteria. These, in turn, are fed on by ciliated protozoans (Madoni 1991) which can reduce the load of pathogenic fecal bacteria to 5% (Curds and Fey 1969). The improved water quality allows dense phytoplankton blooms to develop, an increase in the oxygen levels and the consequent development of rotifers, cladocerans and crustaceans. These being important constituents in the diet of fish, sewage treatment ponds could be profitably used for aquaculture too (Sreenivasan 1980).

The present study was undertaken to understand the dynamics of plankton in relation to nutrient levels during various stages of the sewage stabilization process. The physical and chemical parameters, pH, temperature, dissolved oxygen, soluble reactive phosphorus, total phosphorus and nitrate nitrogen were quantified in a series of sewage stabilization ponds in New Delhi, India. A qualitative analysis of phytoplankton and a quantitative analysis of phytoplankton (as chlorophyll-*a*) and of zooplankton (rotifers, cladocerans and copepods) from April, 1992 to January, 1993 were also carried out.

MATERIALS AND METHODS

The stabilisation ponds considered in this study are part of a series of 30 ponds set up for the treatment of discharged domestic waste water before releasing it into the River Yamuna. Each pond has a surface area of 0.76 hectares and a maximum depth of 2.5m. There are, in addition to other ponds, four rows with four ponds in each set up in parallel. Each pond is connected to the other with a 25 cm diameter channel. In this study, I sampled two parallel sets of ponds and an additional pond in the terminal part of the series (nine ponds in total) (Fig. 1). Pond A received the raw sewage; Pond B and Pond C are intermediate ponds in the series and Pond D is the terminal one in the series from which water enters the river. Corresponding ponds of each set served

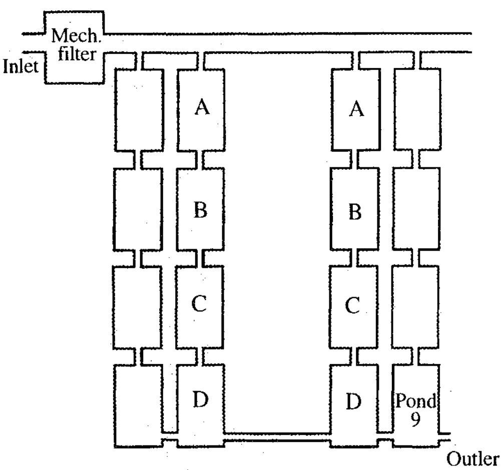

Fig. 1. Outlay of the section of the sewage stabilisation ponds used in the present study (ponds not drawn to scale). Before the raw sewage enters the ponds it passes through a mechanical filter. The two series of ponds are seperated by a public road, approximately a kilometer in length.

as replicates and data obtained from them were pooled to derive mean value.

All the ponds were sampled monthly, between 09:00-11:00 hrs. Water samples were collected by taking sub-surface water, 2-3m away from the edge of the pond using a 5 l capacity plastic bucket to which was attached a long rope. Since the water bodies were shallow, variations in the measured parameters in relation to depth were assumed to be insignificant. Samples were collected from two different sites in each pond and pooled for further analysis.

pH, temperature and dissolved oxygen (measured using a DO meter (Yellow Springs Instruments, Model 54 ARC)) were recorded in the field. A separate sample of pond water was collected for the analyses of nitrate nitrogen, phosphorus and chlorophyll-*a* in the laboratory, which was done within two hours of collection. Nitrate levels were estimated using the phenol disulphonic acid method (Taylor 1958). The reactive and total phosphorus components were estimated by the ammonium molybdate-stannous chloride method (APHA 1989). Chlorophyll-*a* was extracted using a 2:1 (v/v) mixture of chloroform and methanol following Wood (1985).

For collecting zooplankton, 20-50 l of water from each pond, pooled from different sites, was filtered through a 53μm nytex sieve and preserved in the field with 8% buffered formalin. Samples of 100 ml were collected from each pond separately for qualitative analysis of phytoplankton. These samples were fixed in Lugol's solution and later identified to the genus level using Prescott (1951) and Edmondson (1959). Zooplankton were identified, as far as possible to species level, using standard references (Koste 1978; Michael and Sharma 1988; Sehgal 1983). The zooplankton taxa were quantified separately using 2-4 replicate samples on a 1ml capacity Sedgewick-Rafter Cell.

RESULTS

The pH in all the ponds throughout the study ranged from 7.4-8.5. A maximum water temperature of 37 °C was recorded in June and a minimum of 15 °C in January. The level of dissolved oxygen in Pond A was less than 2 mg l^{-1} for most of the sampling period except for two peaks in August and November during which, too, the level was below 4 mg l^{-1} (Fig. 2). Concentrations of dissolved oxygen in Ponds B and C followed similar trends, fluctuating around 6 mg l^{-1} until June with a sharp decline in July. From September until the end of the observations, DO levels were below 4 mg l^{-1}. They were highest in Pond D with a maxima of 10 mg l^{-1}. Trends in fluctuations of dissolved oxygen levels followed patterns similar to Ponds B and C.

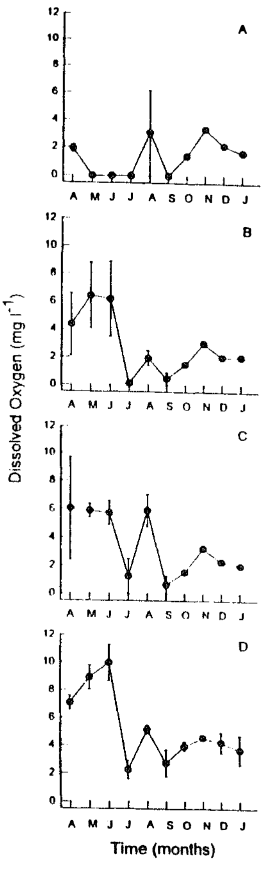

Fig. 2. Variations in the concentration of dissolved oxygen (mg l-1) in relation to time. A represents the initial pond, B and C intermediate ponds and D the final pond in the series. Values shown are mean ± SE based on two replicates.

The concentrations of both soluble reactive phosphorus (SRP) and total phosphorus (TP) were high in all the ponds (Figs. 3 and 4). Values of the former ranged between 1.2-2.0 mg l^{-1} while those of the latter between 2.0-3.5 mg l^{-1}. Figure 5 shows that all the ponds had low levels of nitrate nitrogen (NO_3-N) (0.075-0.30 mg l^{-1}) as compared to phosphorus. The ratio of SRP to NO_3-N was less than 0.5 for a greater part of the sampling period.

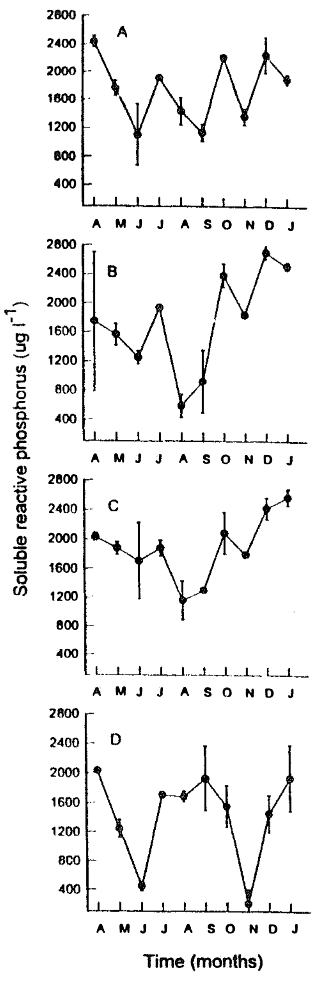

Fig. 3. Variations in the concentration of soluble reactive phosphorus (µg l^{-1}) in relation to time. A represents the initial pond, B and C intermediate ponds and D the final pond in the series. Values shown are mean ± SE based on two replicates.

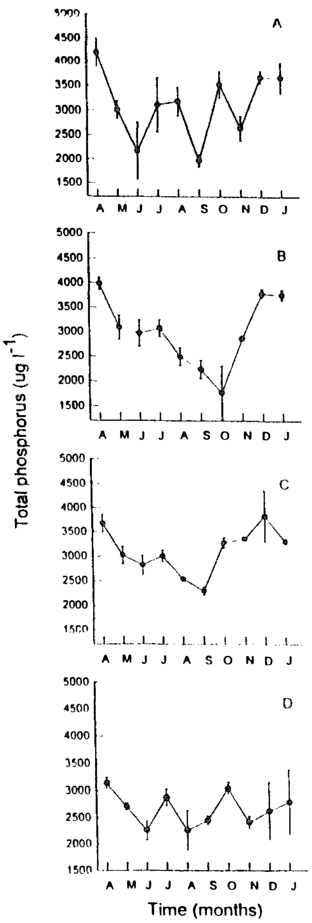

Fig. 4. Variations in the concentration of total phosphorus (µg l-1) in relation to time. A represents the initial pond, B and C intermediate ponds and D the final pond in the series. Values shown are mean ± SE based on two replicates.

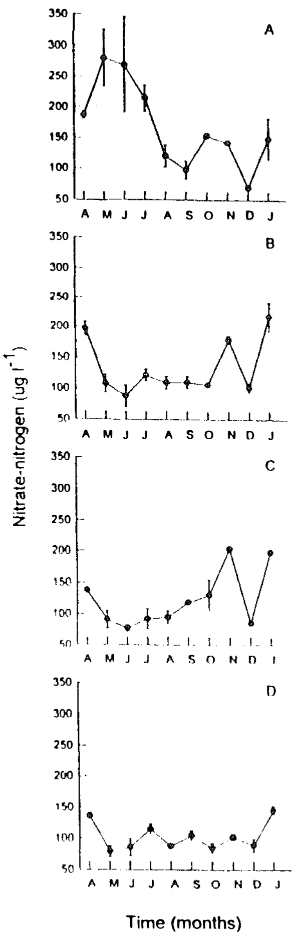

Fig. 5. Variations in the concentration of nitrate nitrogen (µg l-1) in relation to time. A represents the initial pond, B and C intermediate ponds and D the final pond in the series. Values shown are mean ± SE based on two replicates.

The predominant genera of phytoplankton observed in the ponds during the study were *Actinastrum, Ankistrodesmus, Closterium, Chlorella, Euglena, Micratinium, Microcystis, Osillatoria,Pandorina, Phacus, Scenedesmus, Sphaerocystis, Spirulina,* and *Tetraedron.* There were blooms of phytoplankton in all the ponds during June. In Ponds A and B, there were blooms of *Euglena* and *Pandorina* respectively and in Ponds C and D of *Spirulina* and *Oscillatoria.* On an average, chlorophyll-a concentrations were higher in Ponds B and C than D (Fig. 6). Pond D had a bloom of *Microcystis* in July which was replaced by *Oscillatoria* in September and October. In November this was replaced by *Euglena, Phacus, Pandorina* and *Chlorella.* In December and January, water quality in all the ponds deteriorated to levels where almost no algae were found even in the terminal ponds of the series.

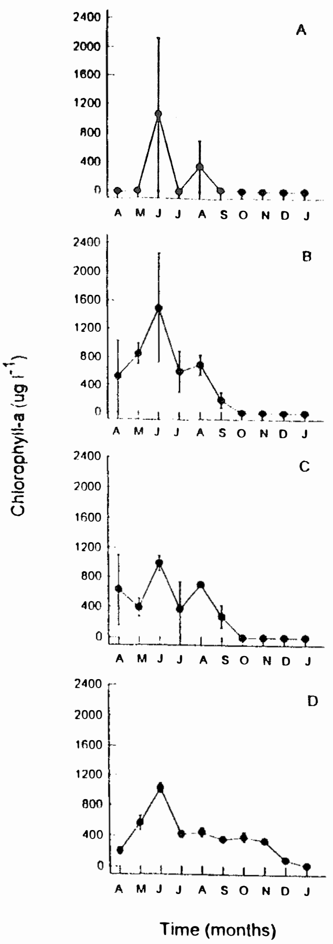

Fig. 6. Variations in the concentration of chlorophyll-*a* (μg l^{-1}) in relation to time. A represents the initial pond, B and C intermediate ponds and D the final pond in the series. Values shown are mean ± SE based on two replicates.

Among zooplankton, this study focussed on copepods, cladocerans, and rotifers. These included *Mesocyclops thermocyclopoides, Ceriodaphnia cornuta, Moina micrura, Daphnia carinata, Asplanchna intermedia, Brachionus angularis, B. bidentatus, B. budapestinensis, B. calyciflorus, B. rubens, Cephalodella* spp., *Epiphanes macroures, Filinia longiseta, Hexarthra mira, Lecane bulla, L. unguitata, Lepadella* spp., *Polyarthra vulgaris, Rotaria rotaria,* and *Trichotria tetractis*. However, only *Mesocyclops thermocyclopoides, Moina micrura, Asplanchna intermedia, Brachionus angularis, B. budapestinensis, B. calyciflorus, Filinia longiseta* and *Hexarthra mira* were found in most ponds for a greater duration of the sampling period; the others were sporadic in appearance. These have been represented in Figs. 7 and 8. Since Pond A was virtually devoid of zooplankton, it has not been represented in the figures.

Among the crustaceans, copepod (nauplii and adult) densities were highest (4356 ind.l^{-1}) in Pond D and almost absent in Pond B while those of *M. micrura* were steadily high in Pond C for a greater part of the sampling period (Fig. 7). Consistently higher densities of most rotifer species were found in Pond D and the lowest in Pond B. *Filinia longiseta* (4930 ind.l^{-1}) and *Hexarthra mira* (4622 ind.l^{-1}) showed the highest abundances (Fig. 8). There was no significant correlation between the density of rotifers and crustaceans in any of the ponds sampled ($p>0.05$).

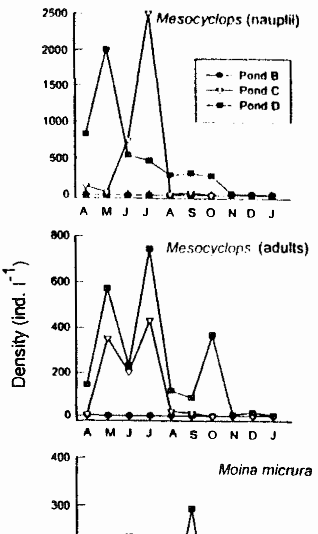

Fig. 7. Variations in the densities of *Mesocyclops* nauplii, *Mesocyclops* adults and *Moina micrura* in Ponds B, C and D in relation to time. Note differences on Y-axis scale.

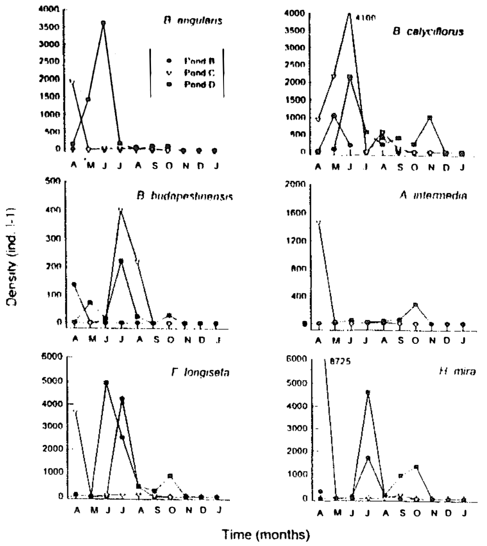

Fig. 8. Variations in the densities of *Brachionus angularis, B. calyciflorus, B. budapestinensis, Asplanchna intermedia, Filinia longiseta* and *Hexarthra mira* in Ponds B, C and D in relation to time. Note differences on Y-axis scale.

DISCUSSION

Hypertrophic systems have higher inputs of nutrients particularly phosphorus and nitrogen. However, nitrogen availability to phytoplankton may decrease particularly due to low recycling rates at the sediment surface and removal of nitrate by the nitrification-denitrification process which is speeded up at higer temperatures (Leonardson and Ripl 1980). This limitation leads to the development of cyanobacteria, some of which can fix atmospheric nitrogen while others, though lacking heterocysts, are superior competitors (Sevrin-Reysacc and Pletikosic 1990). In this study too, I found that nitrate levels were more than an order of magnitude lower than those of phosphorus (Figs. 3-5). However, the nitrate levels were highest in Pond A as compared to Ponds B, C and D. This was probably due to lower algal growth in the Pond A.

In June, when the water temperature was the highest, there were algal blooms in all the four ponds. While in Pond A and B, these were of *Euglena* and *Pandorina* respectively, in Ponds C and D, they were of *Spirulina* and *Oscillatoria*. Flagellates feed efficiently on bacteria with grazing rates as high as 0.2 – 20 X 10^6 bacteria per litre per hour (Vaqué and Pace 1992). Extensive studies have also shown that inedible algae develop in response to zooplankton grazing pressure (Haney 1987). From figures 7 and 8, it is evident that zooplankton densities were higher in Pond C and D as compared to Pond B. This could be one of the factors that led to the development of cyanobacteria in the former ponds and of the edible green alga in the latter.

It has been well documented that in the presence of high densities of crustacean zooplankton, rotifers suffer from both exploitative and interference competition (Gilbert 1988). Therefore, under food limiting conditions, a significant negative correlation is evident between rotifer and crustacean zooplankton densities. In this study, such a relation was not evident because of the hypertrophic nature of the ponds leading to an abundant food supply.

Bacterial load in sewage stabilization ponds can be very high and to a large extant this is controlled by the development of high densities of ciliated protozoans and flagellates (Curds and Fey 1969; Rivera *et al.* 1986, 1987; Madoni 1991; Vaqué and Pace 1992). Zooplankton, particularly cladocerans and rotifers are also known to feed efficiently on bacteria (Vaqué and Pace 1992, Starkweather *et al.* 1979). In this study too, the highest densities among rotifers were reached by *Hexarthra mira* and *Filinia longiseta* which are predominantly bacterivores (Koste 1978). In studies done elsewhere in Asia (Green and Lan 1974) on sewage-stabilization ponds, bacterivorous species such *as Brachionus calyciflorus, Hexarthra mira, Filinia longiseta* and *Epiphanes macrourus* form the bulk of the rotifer fauna. Therefore, even in the absence of edible green algae, high densities of zooplankton can be maintained due to the high bacterial load (Uhlmann 1980).

This study showed that the densities of rotifers, cladocerans and copepods were consistently higher in the terminal ponds of the system, particularly during the summer months. These conditions are conducive for the cultivation of fish especially during the summer months. Fish cultivation, in addition to increasing the productivity of the ponds (up to 9 ton/ha of carps and *Tilapia* has been produced in such a system in India), can also help to control unsightly cyanobacterial blooms and mats by what has been termed as 'biological stripping' (Sreenivasan 1980). Sewage stabilization ponds can therefore be used effectively, not only to reduce the untreated organic load into natural water bodies and prevent eutrophication but also to increase economic benefits through aquaculture.

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RESUMEN

Se registraron las variaciones de parámetros físico-químicos y la structura de la comunidad planctónica de varias lagunas de estabilización de aguas residuales urbanas en Nueva Delhi (India) desde los meses de verano hasta invierno de 1992-1993. Las variables físicas y químicas cuantificadas fueron temperatura, pH, oxígeno disuelto, fósforo reactivo soluble, fósforo total, nitrógeno como nitrato y clorofila-*a*. También se registró un análisis cualitativo del fitoplancton en todas las lagunas. Del zooplancton se identificó y cuantificó rotíferos, cladóceros y copépodos. Las observaciones se hicieron mensualmente. Las concentraciones de fósforo reactivo soluble, fósforo total y nitrógeno como nitrato oscilaron entre 1.2-2.0 mg l^{-1}, 2.0-3.5 mg l^{-1} y 0.075-0.30 mg l^{-1}, respectivamente. Aunque no hubo diferencias significativas en las concentraciones de nutrientes entre los cuerpos de agua, las lagunas que recibían las aguas sin tratamiento tuvieron primero niveles indetectables de clorofila *a* la mayor parte de período del muestreo. En la medida que las aguas pasaban en la serie de lagunas, su calidad mejoró y finalmente, mantuvo altas densidades de zooplancton. Se observaron poblaciones masivas de *Euglena, Pandorina, Spirulina* y *Oscillatoria.* Las especies de rotíferos comúnmente encontradas fueron *Brachionus calyciflorus, Hexarthra mira* y *Filinia longiseta.* Los cladóceros y copépodos estuvieron representados, casi exclusivamente por *Moina macrocopa* y *Mesocyclops thermocyclopoides,* respectivamente.

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