Hydrobiology of Wastewater-fed Man-made Lotic Fish Culture Ponds in Relation to Pollution Physico-Chemical Characteristics

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The present investigation was undertaken with the aim to study the importance of different physico-chemical parameters of water related with recycling of organic waste through aquaculture in a man-made lotic biological sewage treatment system. Water samples were collected once a month from subsurface area of four serially made maturation cum fish ponds from September 1995 to August 1997. The levels of parameters such as water temperature, transparency, pH, dissolved oxygen, free carbon dioxide, total alkalinity, total hardness, calcium hardness, chloride ion, nitrite nitrogen, nitrate nitrogen, ammonium nitrogen, orthophosphate, biochemical oxygen demand, dissolved organic matter, and primary productivity do not significantly indicate a pollution problem. Although higher levels of carbon dioxide and lower levels of dissolved oxygen caused asphyxiation in early hours of some days, fish mortality was not observed probably due to flowing nature of water.

Keywords: Sewage, flow through, aquaculture, carp, abiotic factors

The use of aquaculture for the purpose of wastewater treatment to improve the quality of sewage effluent prior to its release to the land and or any aquatic body has been practiced for a relatively short time. Perhaps the best known example of this practice is the culture of carp (Cyprinus carpio) in wastewater ponds in Germany (Bardach et al.1972 Metcalf & Eddy 1979) at the end of 19th century and independently in Calcutta in 1930 which has now the largest wastewater-fed aquaculture system in the world (Edwards 1985). At present sewage is reused in well defined sewage-fed fisheries in India, particularly in West Bengal, the only state where sewage is widely used for fish culture.

Utilization of sewage for fish culture has attracted the researchers not only for the vast possibility of fish production, but also to check the reduction of pollution load. Since the traditional treatment of sewage involves expensive installations, a second thrust was given to treat the sewage biologically, involving different ponds in the series.

In India, extensive work has so far been done on physico-chemical and biological nature of sewage-fed fish ponds by several workers at different times (Nair 1944a, Sreenivasan 1967, Ghosh et al. 1974, Olah et al. 1986, Rajan & Raj 1995, 1996, Manna et al. 1998a) in closed system. However, information on the physico-chemical nature of lotic sewage-fed fish ponds is too little (Manna et al. 1997b, Manna & Bhowmik 1998a)
In view of paucity of such information, present investigation was undertaken with the aim to evaluate the limno-chemical nature of man-made lotic fish culture ponds in relation to pollution in a comprehensive manner.

About the study area

Kalyani sewage treatment plant is located in Kalyani town (22°58’- 0’ N latitude and 88°26’- 58’ E longitude) on the South Western part of Nadia District, West Bengal, India. It is situated at a distance of 50 km from Calcutta. Kalyani is a planned town mainly established for residential purpose. The population is 7.2 x 10^7 million (in 1991) and as such the total quantity of sewage at the present level of water consumption comes to 16.8 million liter per day (MLD). This sewage treatment plant is under the supervision of Public Health Engineering Directorate and can cater a total of 17.0 MLD of effluent. The traditional treatment plant commissioned in 1954 has a capacity to treat 11.0 MLD of raw sewage through bar screen, grit chamber, primary clarifier, secondary clarifier, trickling filter, sludge lagoons, and drying beds. The additional 6.0 MLD of sewage is being treated through a biological treatment system consisting of stabilization ponds, facultative ponds and maturation cum fish ponds. The low cost biological sewage treatment system is man-made and started functioning in November 1993. Fish culture operation is carried out in maturation ponds by a co-operative fishermen society namely Matsyagandha Fish Production Group since June 1994.

Seasonal demarkation in study area

The seasons are distinctly demarcated in the tropical countries. In West Bengal, the winter is characterized by lower air temperature, shorter day length and less rain fall while in summer higher temperature, occasional rain and longer day length are features of the seasons. Shorter sunshine and higher relative humidity with appreciable rainfall are characteristic features of monsoon or rainy season. Autumn is characterized by moderately hot dry and cooler night hours.

Although West Bengal is customarily characterized as having six seasons in a year only four of the seasons could be differentiated. These are post monsoon/autumn (September, October, November), winter (December, January, February), pre-monsoon/summer (March, April, May) and monsoon (June, July, August).

Materials and Methods

Selection of sampling site

Kalyani sewage treatment through biological means were selected for the study. The household wastewater is collected through underground sewerage, passed through a series of eight ponds (two anaerobic, two facultative, and four maturation cum fish ponds namely P1, P2, P3 and P4) and finally discharged to the river Hooghly (Figure 1). The inlet and outlet of each pond placed diagonally where water flows in a criss-cross way and always maintained a continuous flow-through system (lotic). Sampling of water was restricted only to serially made four maturation cum fish ponds. The annual average depth of all fish pond was 150 ± 3 cm.

Sample collection and analysis

Subsurface water samples were collected from four fish ponds during morning (0700 to 0800 hrs) at a monthly interval for a period of two years commencing from September 1995. Samples were analyzed for water temperature by mercury thermometer, transparency by Secchi disc method, pH using an electronic portable pH meter (Systronics model – 323) following Wetzel...
(1983). Free carbon dioxide was estimated in the field by filtering the sample with N/44 standard sodium carbonate solution using phenolphthalein as indicator following standard methods (APHA 1992). Fixation of water samples in BOD bottles for dissolved oxygen analysis by Winkler’s method and the dark and light bottles technique for analysis of primary productivity (Welch 1948) were done in the field while the titration was performed in the laboratory. Estimation of other chemical parameters like total alkalinity by titrimetric method (phenolphthalein and methyl orange method), total hardness and calcium hardness by EDTA method, chloride, nitrate nitrogen and nitrate nitrogen by colorimetric method, ammonium nitrogen (NH$_4$-N) by phenate method, orthophosphate by stannous chloride methods, BOD by incubating the sample in the BOD incubator (VISWD MDC-901) at 20°C for 5 days, were done following standard methods (APHA 1992). Dissolved organic matter (DOM) was measured by potassium permanganate consumption method (Jhingran et al. 1988).

Statistical analysis

On the basis of fish production potential (Manna 1999) it is significant to mention that out of all studied ponds only P$_3$ has been chosen for an in depth study to find out the correlation of different parameters. Pearson’s correlation coefficients were calculated to evaluate the parametric relationships. Significance difference was determined using the student’s ‘t’ distribution at 5%, 1% and 0.1% level of probability.

Results

Temperature and transparency

Water temperature of ponds showed a marked variation during the period of investigation. As the ponds are inter-connected the water temperature remained almost the same in all the ponds under investigation. Generally the range of variation of water temperature was 22.3°C (minimum) in January 1997 to 33.5°C (maximum) in June 1996.

The lowest peak of transparency value was 7.1 cm in P$_1$, 7.4 cm in P$_2$, 7.2 cm in P$_3$ and 7.0 cm in P$_4$ in May 1996 while the highest peak of it was recorded 23.4 cm in P$_1$ in November 1996, 20.2 cm in P$_2$, 29.2 cm in P$_3$ and 34.2 cm in P$_4$ in March 1996. Hence, no rhythmic pattern in seasonal variation of transparency values could be established as shown in figure (Figure 2A). Ponds showed an increasing trend of transparency value from P$_1$ to P$_4$ throughout the study period.

pH

Water in the experimental ponds was slightly alkaline. The range value of pH was 7.1 – 8.0 in P$_1$, 7.1-8.3 in P$_2$, 7.2-8.4 in P$_3$ and 7.2-8.5 in P$_4$. A lower pH value was recorded during post monsoon while higher pH value was recorded in pre-monsoon of first year study and in winter of the following year (Figure 2B).

Dissolved oxygen

The dissolved oxygen (DO) value of ponds showed wide range of variation, being 0.86-6.24 mg/L in P$_1$, 1.05-7.15 mg/L in P$_2$, 1.21-8.12 mg/L in P$_3$ and 0.94-4.07 mg/L in P$_4$. In first year of study the seasonal variation of DO showed lower values in post monsoon and this continued to winter (Figure 2C), whereas maximum values recorded in pre-monsoon. In second year post monsoon also registered lower values of DO in pond water, while winter showed higher DO values and this followed by pre monsoon. So the ponds showed a unimodal pattern of seasonal variations in DO concentration.

Free carbon dioxide and total alkalinity

All the ponds showed higher values of free carbon dioxide (CO$_2$) during the study period. The range value of CO$_2$ was 10.5-84.5 mg/L in P$_1$, 6.0-55.0 mg/L in P$_2$, 6.4-46.4 mg/L in P$_3$ and 6.4-36.0 mg/L in P$_4$. The values of CO$_2$ exhibited an erratic fluctuation in different seasons (Figure 2D).

There were marked variations in total alkalinity values in the fish pond, being 117.0-391.0 mg/L in P$_1$, 96-365 mg/L in P$_2$, 82.4-362.0 mg/L in P$_3$ and 77.0-360.0 mg/L in P$_4$. The highest peak of total alkalinity was observed in winter of first year while lowest value of total alkalinity was recorded in pre-monsoon of investigation period (Figure 2E).

Total hardness and calcium hardness

The variation of total hardness was 96.0 mg/L in May 1996 to 352.0 mg/L in December 1995 in P$_1$, 100.0 mg/L in May 1996 to 282.0 mg/L in December 1996 in P$_2$, 90.0 mg/L in May 1996 to 246.0 mg/L in November 1996 in P$_3$ and 86.0 mg/L in May 1996 to 241.0 mg/L in March 1996. An erratic pattern in seasonal variation of total hardness values of ponds was established (Figure 2F).

Wide range of variation in calcium hardness concentration was observed in all ponds under investigations. The range value recorded to 70.0-190.0 mg/L in P$_1$, 62.0-175.0 mg/L in P$_2$, 61.0-173.0 mg/L in P$_3$ and 50.0-162.0 mg/L in P$_4$. Likewise total hardness, calcium hardness showed no definite trend of seasonal variation (Figure 2G).

Chloride ions

Hydrobiology of Wastewater-fed Lotic Fish Ponds
Figure 2. Seasonal fluctuations of different hydrological parameters viz. transparency (A), pH (B), dissolved oxygen (C), carbon dioxide (D), orthophosphate (E), total hardness (F), calcium hardness (G) and chloride ion (H).
Ponds showed higher values of chloride ions throughout the study period. The range value of chloride ions was recorded 38.4-150.0 mg/L in P₁, 38.0-148.0 mg/L in P₂, 37.0-149.0 mg/L in P₃, and 37.8-147.0 mg/L in P₄. Higher values of chloride ions were observed in winter and being maximum in pre-monsoon of the study period, whereas lower values of chloride ions were recorded in monsoon and post monsoon (Figure 2H). Hence, a rhythmic pattern in seasonal variations of chloride ions concentration could be established.

Available nitrogen
Nitrogen in water is available as nitrate nitrogen and ammonium nitrogen. Nitrite nitrogen showed a considerable variation among the ponds. Their range values were 0.065-1.005 mg/L in P₁, 0.111-0.882 mg/L in P₂, 0.1-1.003 mg/L in P₃ and 0.096-1.07 mg/L in P₄. Ponds showed no rhythmic variation of nitrite nitrogen concentration in different seasons of two years study (Figure 3A).

The minimum and maximum concentration of nitrate nitrogen was 0.601 mg/L and 7.44 mg/L in P₁, 0.594 mg/L and 6.733 mg/L in P₂, 0.539 mg/L and 6.733 mg/L in P₃, and 0.525 mg/L and 4.668 mg/L in P₄ respectively. Nitrate nitrogen concentration in all fish ponds depicted a unimodal pattern of seasonal fluctuation (Fig.3B). Higher values of nitrate concentration in all ponds were observed at late winter with highest peak in pre-monsoon, while monsoon and post monsoon recorded the lowest values (Figure 3B).

The values of ammonium nitrogen showed a high range of variation in all fish ponds. The values ranged from 0.204-10.2 gm/L in P₁, 0.201-9.69 mg/L in P₂, 0.2-8.67 mg/L in P₃, and 0.153-9.18 mg/L in P₄. Generally the maximum peak of ammonium nitrogen was recorded during monsoon and the minimum values in winter in all the ponds (Figure 3C).

Orthophosphate
The minimum and maximum value of available phosphorus in form of orthophosphate was recorded 0.086 mg/L and 0.89 mg/L in P₁, 0.072 mg/L and 0.8 mg/L in P₂, 0.07 mg/L and 0.76 mg/L in P₃ and 0.056 mg/L and 0.715 mg/L in P₄ respectively during two years of study.

Seasonal variation of orthophosphate registered highest peak during post monsoon in all ponds while winter showed the lowest values during two years of investigation (Figure 3D).

Biochemical Oxygen Demand (BOD) and Dissolved Organic Matter (DOM)
The values of BOD in all ponds ranged from 12.0-22.6 mg/L in P₁, 12.08-20.7 mg/L in P₂, 11.6-18.6 mg/L in P₃ and 10.8-17.9 mg/L in P₄. Ponds showed higher BOD value in monsoon followed by post monsoon, while lowest value of BOD was recorded in winter (Figure 3E).

In twenty four months of study the lowest value of DOM was recorded 4.0 mg/L in P₁, 3.6 mg/L in P₂, 3.0 mg/L in P₃ and 2.4 mg/L in P₄ during March 1997, whereas the highest value of DOM was 14.7 mg/L in P₁, 13.6 mg/L in P₂, 12.8 mg/L in P₃ in August 1997 and 13.0 mg/L in P₄ in February 1997. The concentration of DOM in all ponds generally depicted a unimodal pattern of seasonal fluctuation, the maximum values being recorded in monsoon, while minimum in post monsoon period (Figure 3F).

Primary productivity
The gross primary production (GPP) value recorded minimum and maximum (0.0553 mg C/L/h and 1.7603 mg C/L/h in P₁, 0.0703 mg C/L/h and 1.8841 mg C/L/h in P₂, 0.0751 mg C/L/h and 1.6724 mg C/L/h in P₃, and 0.0532 mg C/L/h and 1.5686 mg C/L/h in P₄ respectively) in August 1996 and in February 1997 respectively in all ponds studied. The first peak appeared in pre-monsoon of first year following second peak in winter, continued up to pre monsoon of second year study (Figure 3G). Like the GPP, the net primary production (NPP) showed similar pattern of seasonal fluctuation (Figure 3H). The range value of which was 0.0243-1.4678 mg C/L/h in P₁, 0.0393-1.4803 mg C/L/h in P₂, 0.0375-1.0553 mg C/L/h in P₃ and 0.0213-0.8546 mg C/L/h in P₄.

 Interaction of Abiotic Factors
Seasonal changes of abiotic parameters are somehow interrelated. Simple correlation between limno-chemical parameters of fish pond is shown in Table 1. It has been found that water temperature showed significant positive correlation with nitrite nitrogen (P<0.01) and ammonium nitrogen (P<0.05). The negative relationship of water transparency with DO (P<0.01), GPP (P<0.01) and NPP (P<0.01), while positive relationship with alkalinity (P<0.001), carbon dioxide (P<0.01) and total hardness (P<0.01) was highly evident. The pH value of pond water exhibited positively significant correlation with nitrate nitrogen (P<0.05) and NPP (P<0.05) while inverse correlation with alkalinity (P<0.05). DO registered significantly negative relationship with alkalinity (P<0.05) and total hardness (P<0.01), whereas direct correlation with nitrate nitrogen (P<0.05). Relationship of GPP and NPP with DO where found significantly high (P<0.05). The relationship of alkalinity with nitrate nitrogen (P<0.05), GPP (P<0.01) and NPP (P<0.001) were found to be statistically negative. Although nitrogen and phosphorus of pond water did not show any significant effect on primary production the relationship of total hardness, however, with GPP and NPP is well established (p<0.01).
Figure 3. Seasonal fluctuations of different hydrological parameters viz. nitrite nitrogen(A), nitrate nitrogen(B), ammonium nitrogen(C), orthophosphate(D), BOD(E), DOM(F), GPP(G) and NPP(H).
Table 1. Pearson’s correlation coefficient \( r \) between hydrological parameters of fish pond. Number of observations \( n \) in each parameter is 24. Statistical significance was evaluated at 5\%, (*) 1\% (**) and 0.1\% (***) level of probability.

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1 = Water temperature, 2 = Transparency, 3 = pH, 4 = Dissolved oxygen, 5 = Free carbon dioxide, 6 = Total alkalinity, 7 = Total hardness, 8 = Calcium hardness, 9 = Chloride ion, 10 = Nitrite nitrogen, 11 = Nitrate nitrogen, 12 = Ammonium nitrogen, 13 = Orthophosphate, 14 = Biochemical oxygen demand, 15 = Dissolved organic matter, 16 = Gross primary production, 17 = Net primary production.
A significant effect of DOM on BOD values (P<0.001) is exhibited in fish pond. A parallel relationship between GPP and NPP is highly evidenced (P<0.001).

Discussion

It is generally believed that temperature is one of the most important factors in an aquatic environment. In fact, no other single factor has so many profound influences and so many direct and indirect effects upon its productivity (Welch 1952). As a rule, the maximum temperature showed in summer and minimum in winter. Huet (1972) stated that warm water fishes can grow well in temperature ranging from 10°C-35°C. Temperature below 16.7°C and above 39.5°C prove fatal to most fishes including carps (Jhingran 1991). The range of temperature in the present investigation was not far exceeds the said values and did not make any lethal effect on organisms.

In ponds the variation of transparency may be due to suspended inorganic substances, such as silt and clay or planktonic organisms. Excessive growth of planktonic organisms was recorded in May 1996, which reduces maximum light penetration. It has been stated that Secchi disk visibility of 40-80 cm to be desirable for fresh water ponds while in no cases below 20 cm is desirable for successful fish culture (Boyd 1982). However, in the present study the transparency values were recorded below the said values in most of the months, which may be permissible in sewage fed ponds in tropical countries. Increasing trend of transparency values could be attributed to the biological activities and sedimentation of the suspended "microfines”.

pH of water is the resultant effect of many chemical and biochemical reactions and it is considered as an index of pond productivity (Huet 1972). In almost every instance where the water is neither acidic nor very alkaline, it may justly be assumed that the pH is regulated by the CO$_3^2$-HCO$_3^-$ system (Hutchinson 1957). Slightly lower pH value of morning water samples in wastewater pond may be due to higher organic load of the pond water, which through their decomposition processes, probably contributed to reduction in pH values (Manna & Bhowmik 1998c). However, photosynthetic uptake of carbon dioxide and bicarbonate, the later being substituted for hydroxyl ions, which explains instead of lowering of pH value during the periods of intense photosynthetic activity. Thus maintained a fairly favourable range of pH in the ponds. Higher pH value during pre monsoon might be due to concentration of sewage through higher degree of evaporation. A pH range of 6.5-9.0 was found to be suitable for pond culture (Swingle 1947). It may be inferred that the pH level of the studied ponds was favourable for fish culture.

The wide variation of DO in pond water is crucial for fish. Olah et al. (1986) noted a wide fluctuation of DO ranging from 4.0-19.0 mg/L in city sewage-fed fish ponds of Hungary and 3.2-16.4 mg/L at Calcutta. DO less than 2.0 ppm was also reported by several authors (Ghosh & George 1989, Manna et al. 1997b, Manna & Bhowmik 1998c in the late night to early morning hours. Their findings are in agreement with the present study. That is might be due to almost complete utilization of oxygen during night hours by phytoplankton and other pond biota and also for the decomposition of a good amount of detritus. Although low DO prevailed for few hours in the ponds, fish mortality, however, was not noticed due to running nature of water as reported by Manna and Bhowmik (1998c). During monsoon relatively high content of silt and clay particles in sewage water may increase the water turbidity. In addition, higher decomposition rate and lower solar radiation might decrease the DO content of pond water in post monsoon. On the contrary, higher solar radiation may enhance photosynthetic activity which resulted to increase DO concentration of pond water during pre-monsoon.

Higher decomposition rate may be reason for higher CO$_2$ level in wastewater fed pond. In spite of daily input of sewage water, the high value of free CO$_2$ was not observed for a long time due to consumption of CO$_2$ through high rate of photosynthetic activity at day time (Saha 1993). Besides, free CO$_2$ plays an important role in fish ponds by producing calcium bicarbonate from calcium carbonate and by maintaining the pH of the water nearly constant through the butter system of CO$_2$-Ca (HCO$_3^-$) system. According to Swingle (1947), presence of free CO$_2$ at a higher level (>15 mg/L) for long duration is detrimental to fishes. In the present observations higher concentration of CO$_2$ caused asphyxiation in early hours of some days during study period but no death of fish was observed which was probably due to running nature of water.

Generally, natural water bodies showed maximum alkalinity in summer and minimum in rainy season (Boyd 1982). Nevertheless, the present findings did not observe the mentioned pattern. Such irregular fluctuation of total alkalinity values in pond might be due to the quality of sewage effluent added daily. The importance of alkalinity in view of its relationship with CO$_2$ for photosynthesis was emphasized. A good production of fish was recorded from a sewage-fed fish pond having total alkalinity values from 200.0 to 385.0 ppm (Ghosh et al 1974). Accordingly, the total alkalinity values of the studied ponds were considered to be favourable for good aquaculture.

Higher concentration of total hardness is indicative of high value of Ca and Mg salts in pond water, expressed as its CaCO$_3$ equivalent (Boyd 1982). It has been
stated that Ca plays an important role in cell division and formation of cell wall of phytoplankton and aquatic plants. Mg is helpful in chlorophyll formation, deficiency of it causes deformities in chlorophyll cell formation i.e. chlorosis. Hence hardness has great importance from the aquaculture point of view. Water body with high total alkalinity and low total hardness may develop problems with high pH during the periods of rapid plant growth (Boyd 1982). Such situation is not observed in present findings. An irregular pattern of seasonal variation of both total hardness and calcium hardness values might be due to sewage water quality as such. Maximum concentration of chloride ion recorded in pre-monsoon might be due to evaporation effect. Contrarily, heavy rainfall is the probable cause of lowering of its concentration during monsoon onwards.

The importance of nitrogen in fish nutrition is well recognized (Heaphy 1962). The results of seasonal changes of nitrate and ammonium form of nitrogen showed that ponds recorded higher concentration of ammonium form of nitrogen than the nitrate form, obviously owing to restricted rate of nitrification in soils under submerged condition, as elaborated by some authors (Chattopadhyay & Mandal 1982). At the onset of pre-monsoon when suitable solar radiation is available, phytoplankton produces large amount of DO. It ultimately helps to increase the rate of nitrification for the formation of more nitrate nitrogen to attain its maximum peak, during monsoon excessive input of sewage water and heavy rains enrich the ponds with organic matter and other nutrients. Their decomposition may require large amount of DO and subsequently increase the ammonium nitrogen level. Of the numerous physical, chemical and biological mechanisms that lead to ammonia nitrogen reduction in ponds, nitrogen assimilation and nitrogen volatilization are perhaps the most significant. Many pond researchers consider that the main mechanism in assimilation into algal cell, leading to the formation and precipitation of insoluble organic complexes (Meron et al. 1972, Ferrara & Avei 1982). Other researchers emphasise that volatilization of ammonia gas from pond surface, specially at high pH and temperature and under well mixed conditions, may provide for a significant amount of ammonia removal (Folkman & Wachs 1972). Owing to such reasons some pioneer authors (Ghosh et al. 1974, Manna et al 1997b) did not observe any adverse effect on fish life in spite of higher ammonia level in sewage-fed fish pond. No adverse effects on ammonia toxicity on fish behaviour could be observed.

Phosphorus is considered to be one of the most important nutrient for maintenance of high productivity in ponds. Inorganic phosphorus as orthophosphate in the investigated ponds revealed a definite pattern of seasonal variation. In post monsoon months, owing to absence of rains, more concentrated sewage effluent was circulated through the pond. The phosphorus concentration in that period are, therefore, found to be markedly higher. Such finding is corroborated with the findings of several authors who (Ghosh et al. 1974, Saha 1993, Manna et al 1997b). Olah et al (1986) reported the value of available phosphorus in water ranging from 0.2 to 0.5 ppm in city sewage-fed fish ponds of Hungary and 0.37 to 4.27 ppm in ponds of Calcutta. A high value of phosphorus ranging from 0.8 to 10.4 ppm in a sewage-fed fish pond is noted by Sreenivasan & Muthuswamy (1979). In the present observation the inorganic phosphate phosphorus content of water was found to be always high.

In natural water body, as a rule, BOD value revealed lower concentration in winter probably owing to lower decomposition rate in low temperature. Present experimental ponds are not in berth of it. Contrarily, BOD values are higher in monsoon and post monsoon obviously due to presence of larger organic load. In wastewater fed ponds the BOD levels are influenced mostly by the amount of wastewater applied and its BOD load. An average BOD levels between 15.0 ppm and 38.0 ppm were observed in some sewage fed ponds of Calcutta (Anon 1988). Saha (1993) recorded BOD values ranged 12.0-40.0 ppm of several sewage-fed fish ponds around Calcutta. Considering all opinions observed BOD levels in the present situation were found within the suitable range (< 50 ppm ) for fish culture.

Primary productivity by phytoplankton is often considered to be productivity of water bodies since it is the major form of organic matter synthesis in aquatic environment. Primary production in form of GPP and NPP showed wide range of variations and their seasonal fluctuation were distinct. Presence of nutrient elements at optimum concentration and thereby production of healthy phytoplankton and algal dominance may be possible reason for high productivity of ponds. Gradual increase of light and temperature in pre-monsoon in comparison to post monsoon and winter stimulates the decomposition rate of organic matters deposited on bottom. This resulted in a higher concentration of nutrients favouring maximum growth rate of phytoplankton leading to higher photosynthesis in pre-monsoon.

It has been found that water temperature showed significant positive correlation with nitrite nitrogen (p<0.01) and ammonium nitrogen (p<0.05). Increased temperature enhances the bacterial decomposition rate at mud surface resulting high concentration of ammonium nitrogen in pond water. In present observations water temperature exhibited direct relationship with GPP and NPP. However, their relationships were not statistically significant since the light reactions are independent of temperature. Similar findings were recorded by several authors (Datta & Choudhuri 1984, Chakrabarti & Asthana 1989), although a significant correlation of
water temperature with GPP (p < 0.05) and NPP (p < 0.1) has been reported (Basheer et al. 1996).

Transparency bears a significant inverse correlation with DO (p < 0.01), GPP (p < 0.01) and NPP (p < 0.01), corroborated with the findings of Datta and Chaudhuri (1984). The positive correlation between pH and NPP (p < 0.05) in fish pond favours the idea that increased photosynthesis by phytoplankton raises the pH of pond water. According to Andersson et al. (1978) photosynthesis raised pH of pond or lake water and favours the physical release of phosphorus from the sediment which will further accelerate the phytoplankton growth. However, pH of pond water in the present situation showed negative correlation with orthophosphate as the phosphorus is not a limiting factor in sewage-fed fish pond.

A significant negative correlation of DO with total alkalinity (p < 0.05) and total hardness (p < 0.01) is supported by the findings of Chattopadhyay et al. (1988) and Chakrabarti & Asthana (1989). DO exhibited a positively significant correlation with nitrate nitrogen (p < 0.05), GPP (p < 0.001) and NPP (p < 0.001) in the fish pond corroborated with the observations of some pioneer authors (Datta & Chaudhury 1984, Basheer et al. 1996). Such relationship support that photosynthesis increases oxygen of pond water and accelerates nitrification (Saha 1993). Significantly negative correlation of total alkalinity with GPP (p < 0.01) and NPP (p < 0.01) in the studied pond agrees with Datta & Chaudhuri (1984) and Verma & Mohanty (1994) that the ponds contained excess concentration of alkalinity which was not essential for phytoplankton growth. The role of total hardness in fish pond is well established due to chlorophyll formation, growth and reproduction of phytoplankton and aquatic vegetation. However, the negative effect of total hardness with GPP (p < 0.01) and NPP (p < 0.01) might be due to excess concentration of total hardness in the ponds.

All the ponds under investigation exhibited higher values of dissolved inorganic nitrogen from sewage that benefits primary production. A significant correlation could not, however, be observed between nitrate nitrogen and primary productivity, which may probably be due to the presence of very high amount of available nitrogen in ponds. There might be comparative limitation of some other nutrients in water and thus hindered the effects of nitrogen on GPP and NPP (Saha 1993). Positive significant correlation of BOD with DOM (p < 0.001) in fish pond indicates the heavy load of organic matter. Generally sewage-fed fish ponds are rich in organic matter (Nair 1944a, Edwards 1985). So requirement of DO for its decomposition is significantly high.

In the present investigation four biologically treated sewage fed fish ponds were undertaken with the aim to evaluate the physico-chemical characteristics of ponds in relation to pollution. A two-year investigation showed that some of the parameters (water temperature, dissolved oxygen, chloride ions, nitrate nitrogen, ammonium nitrogen, orthophosphate, DOM, BOD, GPP, NPP) fluctuated in a rhythmic pattern to some extent. Other parameters (transparency, pH, carbon dioxide, total alkalinity, total hardness, calcium hardness, nitrite nitrogen) exhibited irregularity in their seasonal variations. Most of the parameters tested do not indicate a pollution problem. However, higher levels of carbon dioxide and ammonium nitrogen and lower levels of dissolved oxygen prevailed in some days and caused asphyxiation of fish. Interestingly fish mortality was not observed which might be due to running nature of water.

Water quality largely depend on intake volume of water and water quality. Generally domestic sewage with < 50 ppm BOD value is good for productivity and fish culture. Stocking of fish certainly affect water quality. There must be limitation in stocking density of carp.

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