Acta hydrochim. hydrobiol. **32** (2004) 2, 138–148

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Water Quality Monitoring of Tropical Ponds: Location and Depth Effect in Two Case Studies

The variability in water chemistry of samples taken on a monthly basis (March 1999 to February 2000) from two shallow tropical ponds was studied. The effect of location and pond depth on water chemistry was also examined. The study demonstrated that intra-annual variability in nutrient concentration is high. Thus, a high annual sampling frequency is required to provide representative annual mean water quality data. Routine monitoring during the monsoons is important for studies on dissolved oxygen and macrophyte growth. Significant differences were found between the topmost and bottommost points for samples of dissolved oxygen collected from the deepest part of both ponds. For nutrient analysis (nitrogen and phosphorus), sample from any location was found to be representative of the whole pond.

Monitoring der Wasserbeschaffenheit tropischer Teiche: Effekte von Ort und Tiefe in zwei Fallstudien

Untersucht wird die Variabilität chemischer Probenergebnisse auf monatlicher Basis (März 1999 bis Februar 2000) aus zwei tropischen Teichen (0.4 und 0.3 ha, 1.8 und 2.7 m maximale Tiefe). Dargelegt wird auch der Einfluss der Lage und Tiefe der Probenahme auf die chemischen Ergebnisse. In den Nährstoffkonzentrationen ist die innerjährliche Variabilität groß, weshalb eine hohe Frequenz der Probenahme zur Ermittlung der Wasserqualität notwendig ist. Für die Erfassung der Sauerstoffkonzentration und der Entwicklung des Makrophytenbestandes sind Untersuchungen während der Monsun-Periode wichtig. Zur Wahl der Probestellen ist wichtig, dass für den Sauerstoffgehalt signifikante Unterschiede zwischen Oberflächen- und sedimentnahen Proben bestehen, während hinsichtlich der Nährstoffkonzentrationen keine signifikanten horizontalen oder vertikalen Differenzen auftreten.

Keywords: Water Sampling, Dissolved Oxygen, Nitrogen, Phosphorus

Schlagwörter: Probenahme, Sauerstoffgehalt, Stickstoff, Phosphor

1 Introduction

Aquatic ecosystems are characterized by great variability and complexity which is getting compounded by the increasing impact of human activity. Over the past years there has been a concentration of research efforts on water quality of lakes and rivers [1–4] but not enough attention has been directed to the study of ponds which are more abundant than lakes and rivers in several regions.

Ponds, many of which exist in less developed parts of the world, have many different demands made on them and as a result are more vulnerable to changes in water quality. Despite the high level of public interface and hence the importance of ponds [5] there still remains much to know about them and their function. Moreover, emphasis is now being directed to the study of tropical and subtropical aquatic ecosystems [6, 7] in view of the differences in temperature, primary production, diversity of fauna/flora, and metabolic processes in these waterbodies. Therefore, there is a pressing need to gain ecological knowledge about tropical ponds from properly recorded water quality data. Since it is common practice in monitoring programmes to represent each site by a single sample or in situ measurements at a single station, some studies on water sampling techniques have been conducted in temperate regions [8, 9]. Bennion and Smith [10] also stressed the need for proper sampling design for more reliable water chemistry data sets for use in predictive models of trophic status.

In view of the above, the present research was initiated to study the seasonal variation in water chemistry variables in two tropical ponds. For a representative estimate of the variables, it was also thought appropriate to determine whether location or depth was an important factor in the sampling strategy for water quality monitoring of ponds.

2 Material and methods

2.1 Study site

This investigation was conducted on two small ponds namely, campus pond 203 and pond 206, located in Calcutta, India (22°20′...22°40′ N, 88°10′...88°40′ E) with a tropical monsoon climate. The rainfall data supplied by the Alipur Meteorological Center, Calcutta is given in Figure 1a along with air temperatures. The total annual rainfall during this study period was 265.3 cm.

Both ponds were rectangular in shape with surface areas of 0.4 ha and 0.3 ha, volumes 7258 m^3 and 8136 m^3, and a maximum depth of 4.0 m and 5.0 m, respectively, for pond 203 and pond 206. The ponds have public interface and are surrounded by trees with overhanging branches that add allochthonous organic matter in form of dead leaf litter. They also had a garden center on one side where season flowers are grown during winter. Both ponds were selected such that precipitation and runoff were the only source of nutrients.

2.2 Sampling procedures

The ponds were sampled monthly, using a boat, between 09.00 and 10.30 h during the period March 1999 to February 2000 to study the annual variability and changes during the one year period. Each month there was a week's gap between sampling dates for the two ponds.

Secchi depth readings were recorded from five different locations (four side points and one at the deepest point). Water samples were taken from 1 m below the surface from four randomly selected sampling points (depth 1.5 to 2 m) which were located towards the littoral zone of the pond where vegetation was observed. To check for depth effect, a fifth sampling point was selected at the deepest part of each pond from where samples were collected at 1 m interval from 1 to 4 m water depth in pond 203 and from 1 to 5 m water depth in pond 206. For nitrogen and phosphorus estimation, in addition to the four side points only two samples from the deepest point were taken i.e., 1 m below the surface and 1 m above the bottom. All points were slightly adjusted, when required, with changes in water level and vegetation bed. Visual observations on the macrophyte species present in each pond were also recorded monthly.

2.3 Water analysis

Water transparency was measured from the month of April onwards by Secchi depth. Air and water temperatures, water conductivity, pH, and dissolved oxygen (DO) were measured at each point using a calibrated multiparameter probe attached with a WQC-20A water quality checker (Xebex International Ltd, Tokyo, Japan). Water samples were collected, using a Van Dorn horizontal bottle sampler, for subsequent laboratory determination of total Kjeldahl nitrogen and total phosphorus [11].

2.4 Statistical analysis

Initially, a four way ANOVA model without interaction was applied to the data to check for the existence of significant differences. The model included pond effect, month effect, location effect, and depth effect at the centre location – all of which were in turn nested within the pond effect. It was found after analysis that there is a very significant pond effect and hence it was thought appropriate to perform separate analyses for the two ponds.

The following simplified model, retaining the month effect while pooling the location and depth effect together to call it a sampling point effect, was next fitted to the data

$$Y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij} \quad (1)$$

where Y_{ij} is the observation in the i^{th} month, j^{th} sampling point; μ is the general effect; α_i is the i^{th} month effect (i = 1...12); β_j is the j^{th} sampling point effect (j = 1...J with J = 8 or 9).

Sampling point here represents any point (both location as well as depth) in the spatial topography of the pond from where sampling was conducted. For Secchi depth, sampling point included only the four side aerial locations i.e., $\beta_1 ... \beta_4$ and one central aerial location i.e., β_5 since depth sampling cannot be applied here. For this variable, when location effect was significant, critical difference (C.D.) at 5% level was calculated to study the significant difference between different locations.

For all other variables, sampling point consisted of the four side locations ($\beta_1 ... \beta_4$ being the corresponding parameters at 1 m level) and one central location (β_5 being the corresponding parameter at 1 m level) with its 3 or 4 increasing depths ($\beta_6 ... \beta_J$ being the corresponding parameters). Here, when sampling point effect was found to be significant, it was thought worthwhile to check whether

i) any difference existed amongst various locations at the 1 m level with the corresponding null hypothesis H_{01} = β_1 = ... = β_5, and

ii) any difference existed amongst the central location and its various depths with the corresponding null hypothesis H_{02} = β_5 = ... = β_J.

All statistical procedures used in this study were performed using the S-plus (version 4.5) package [12].

3 Results

3.1 Floristic composition

A monthly record of macrophyte species found in the study ponds is presented in Table 1. Pond 203 had a variety of aquatic macrophytes ranging from three to seven species throughout the study period. Pond 206 was devoid of any flora during the first five months. Thereafter, the species number was low and rose to a maximum of four during the last three months. An association of three species namely *Lemna minor, Nymphoides hydrophylla,* and *Vallisneria spiralis* was present all through in pond 203. Emergent plants were found to propagate after the monsoons and *Alternanthera philoxeroides* covered the shallow water edges of both ponds as the water level increased. This plant was present in both ponds from September 1999 until February 2000.

3.2 Monthly variation in water quality

Fluctuations in the monthly means of some physico-chemical water quality parameters in the two ponds are summarized in Figure 1 b–e and Figure 2 a–f. ANOVA summary table for the statistical model (Eq. (1)) is given in Table 2.

During the period of study the air temperature (Fig. 1 a) was the lowest in January (21 °C) and the highest in April (31.7 °C) while water temperature values (Fig. 1 b) were between 19.9 °C in January to 32.1 °C in April, following an almost similar pattern for most months in both ponds. However, at the onset of summer, when the air temperature shot up from 27 °C in March to 31.7 °C in April 1999, pond 206 which was devoid of any macrophyte flora warmed up much faster (March to April) than did pond 203 (March to June), which had some floating and floating leaved macrophytes like *Lemna minor* and *Nymphoides hydrophylla* (Table 1) covering its surface.

The pattern of change in conductivity and pH values over the seasons was similar in both ponds (Fig. 1c, d). However, both of these variables showed a significant month effect (Table 2) with conductivity values at its highest in summer (i.e., May to June) and dipping from October to December. pH values, on the other hand, decreased during the rainy season.

The Secchi depth visibility (Fig. 1 e) was significantly higher in pond 203 except during the months of August to October, a period of heavy rains (Fig. 1 a) when pond 206 recorded a greater visibility. Secchi depth observations also showed a significant month effect for both ponds (Table 2).

Mean DO values ranged from 1.06 mg L^{-1} (July) to 4.54 mg L^{-1} (April) in pond 203 and from 1.28 mg L^{-1} (September) to 3.83 mg L^{-1} (April) in pond 206 and from Table 2 it can be seen that there was a significant month effect. Seasonal fluctuations for this variable, were quite similar in both ponds with more or less uniform values during summer and winter months (Fig. 2a, b) but dipping considerably during the monsoons. Maximum variability within months was also observed for this variable in both ponds.

From Figure 2c, d it is evident that there was not much variation in the mean total nitrogen concentration of the two ponds except for three prominent spurts in August 1999, October 1999, and January 2000. Within month variation appeared to be relatively minimum (be it location or depth) for

Table 1: Species of macrophytes present in the two ponds during March 1999 to February 2000.

Vorkommen von Makrophyten in beiden Teichen von März 1999 bis Februar 2000.

Month	Pond 203		Pond 206	
	Macrophyte	Species number	Macrophyte	Species number
March	L, N, V	3	–	0
April	L, N, V	3	–	0
May	L, N, V	3	–	0
June	L, N, R, V	4	–	0
July	L, M, N, R, V	5	–	0
August	L, M, N, R, V	5	A	1
September	A, L, M, N, N*, R, V	7	A, N	2
October	A, L, M, N, N*, R, V	7	A, N	2
November	A, L, M, N, N*, R, V	7	A, N	2
December	A, L, M, N, N*, R, V	7	A, E, L, N	4
January	A, L, M, N, N*, V	6	A, E, L, N	4
February	A, C, L, M, N, T, V	7	A, E, L, N	4

Abbreviations:
A: *Alternanthera philoxeroides*, C: *Commelina bengalensis*, E: *Eclipta alba,* L: *Lemna minor,* M: *Marsilea minuta,* N: *Nymphoides hydrophylla,* N*: *Nymphaea pubescens,* R: *Rotala macrandra,* T: *Trapa bispinosa,* V: *Vallisneria spiralis,* – Absent.

this variable except for two months (October 1999 and January 2000) in pond 206. Mean phosphorus content (Fig. 2e, f) ranged from 0.23 mg L^{-1} (February) to 0.92 mg L^{-1} (September) in pond 203 and from 0.17 mg L^{-1} (December) to 1.10 mg L^{-1} (April) in pond 206.

3.3 Location effect

Sampling point effect was found to be significant for the variables water temperature, pH and dissolved oxygen for both ponds and for Secchi depth and conductivity only in pond 203 (Table 2). In pond 203, during the months April, May, November to January, Secchi disk hit the bottom at the side points i.e., along the littoral zone ($\beta_1 ... \beta_4$), while such a phenomenon never occurred in pond 206. This could possibly account for the significant sampling point effect in pond 203 and when critical difference was calculated for this variable (C.D. at 5% = 0.37), it was evident that all the four side locations were significantly different from the central location. For the variables nitrogen and phosphorus, point effect was not significant (Table 2). Evidence in favour of H_{01}, which shows the location effect, was found for all variables for both ponds suggesting that there is no significant difference between different locations at the 1 m level.

3.4 Depth effect

Evidence in favour of H_{02} was found for all variables (excepting for pH and DO) for both ponds suggesting that there is no significant difference between different depths at the central location. The depth profile of DO and pH for both ponds at the central location is shown in Figure 3. A clinograde oxygen distribution accompanied by a decrease in pH values towards the bottom is evident.

In case of DO, there is evidence in favour of H_{01} which implies that different location measurements at 1 m level are similar while H_{02} is rejected: suggesting differences at different depths. Figure 4 a, b show the pair-wise comparison of depths for ponds 203 and 206, respectively. The figures clearly show differences between the topmost and the bottommost depth indicating that depths 1, 2, and 3 are different from depth 4 (bottom depth) in pond 203 and depths 1, 2, 3, and 4 are different from depth 5 (bottom depth) in pond 206.

Graphical diagnostics for the model assumptions for analysis of DO for both ponds were carried out to check normality of errors, heterosedasticity, outliers and goodness of linear fit. The results are given in Figure 5. The three plots in the upper panel correspond to DO values in pond 203 while the lower panel corresponds to DO values in pond 206. In each panel, the residual plots show randomness and approximately constant variance; the Q-Q plots for the standardized residuals against the quantiles of standard normal distribution conform with the normal assumption and the fitted v/s observed values show that the linear model gives a good fit of the data.

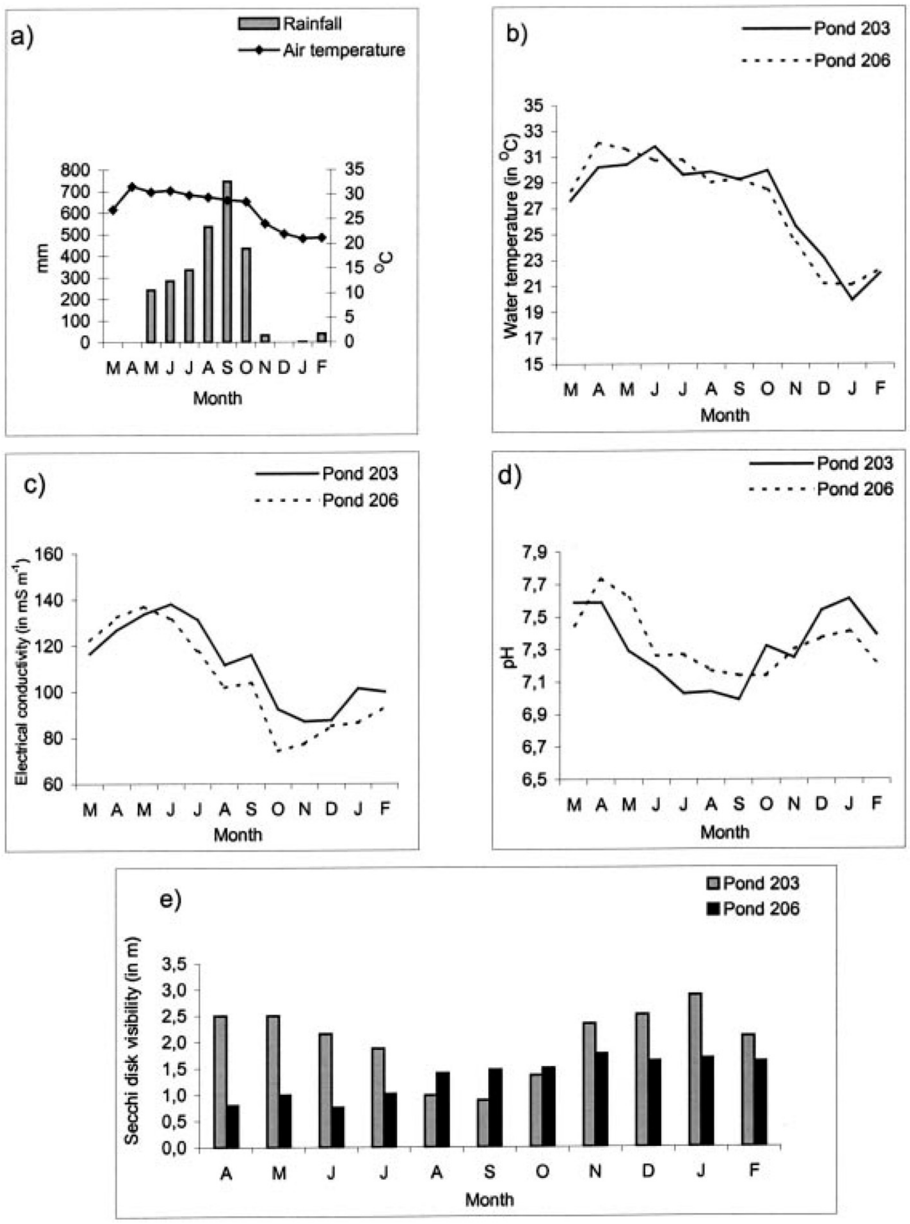

Fig. 1: Monthly fluctuations in mean values of some physico-chemical parameters of two ponds.

Monatliche Fluktuation der Mittelwerte einiger physikalisch-chemischer Parameter der beiden Teiche.

4 Discussion

4.1 Factors contributing to month, location, and depth effect

Annual changes of temperature as is also evident in this study are relatively small compared to diel ones [13] which is in contrast to temperate lakes where seasonal changes of temperature dominate. Lake morphometry (depth and vulnerability to wind stress) as well as its geography (both latitude and altitude) are known to influence the thermal regime of tropical lakes [14] which typically show warm monomictic patterns with variations towards polymixis where the relative depth is low [15].

In a depth-time study of tropical waters, Barbosa and Tundisi [13] reported fluctuations in pH and electrical conductivity. Conductivity values in the present study were similar to those reported by Sreenivasan [16] but higher than those reported by Khondker and Kabir [17] and Zavala et al. [18] for tropical waters. High conductivity values in both ponds during summer could be associated with evaporation while the decreasing trend after monsoons could be a consequence of dilution due to rainfall thereby explaining the significant month effect for this variable (Table 2). Monthly fluctuation of pH values found in this study concur with those reported by Khondker and Kabir [17], Murugavel and Pan-

Table 2: ANOVA summary of evaluation of effects of month and sampling point on water quality parameters of two tropical ponds. Significant values ($p < 0.05$) are in bold.

Zusammenfassung der ANOVA-Ergebnisse zu den Effekten von Probenahmestelle und −tiefe hinsichtlich der Wasserbeschaffenheit. Signifikante Ergenbnisse ($p < 0.05$) fett.

Parameter	Source	Pond 203				Pond 206			
		df	M.S.S	*F* value	*p*	df	M.S.S.	*F* value	*p*
Water temperature	Month	11	112.462	150.392	**0.000**	11	126.664	1068.396	**0.000**
	Point	7	1.972	2.638	**0.018**	8	0.727	6.131	**0.000**
	Residuals	66	0.748			69	0.119		
Secchi depth	Month	10	1.953	13.732	**0.000**	10	0.494	21.016	**0.000**
	Point	4	0.388	2.729	**0.046**	4	0.038	1.632	0.190
	Residuals	32	0.142			32	0.024		
Electrical conductivity	Month	11	2265.703	34.164	**0.000**	11	3300.624	87.394	**0.000**
	Point	7	200.358	3.021	**0.008**	8	13.066	0.346	0.945
	Residuals	66	66.318			69	37.767		
pH	Month	11	0.428	20.290	**0.000**	11	0.251	51.642	**0.000**
	Point	7	0.134	6.352	**0.000**	8	0.032	6.577	**0.000**
	Residuals	66	0.021			69	0.005		
Dissolved oxygen	Month	11	10.241	39.713	**0.000**	11	3.832	20.779	**0.000**
	Point	7	1.832	7.104	**0.000**	8	2.520	13.667	**0.000**
	Residuals	66	0.258			69	0.184		
Total nitrogen	Month	11	578.428	1818.023	**0.000**	11	275.733	12.461	**0.000**
	Point	5	0.103	0.324	0.896	5	34.405	1.555	0.190
	Residuals	50	0.318			50	22.128		
Total phosphorus	Month	11	0.234	2.453	**0.015**	11	0.524	5.096	**0.000**
	Point	5	0.288	3.019	0.190	5	0.186	1.807	0.128
	Residuals	50	0.096			50	0.103		

dian [19] for subtropical and tropical ponds. A low pH value during the rainy season (Fig. 1 d) could be due to the low photosynthetic rate generally associated with cloudy conditions.

During the period, when aquatic macrophytes were totally absent from pond 206 (Table 1), Secchi depth visibility (Fig. 1 e) was rather low (maximum 1 m and minimum in June). Visibility started increasing (> 1 m) from the month of August onwards which coincided with the gradual appearance of aquatic plant species in this pond. Pond 203 had a rich aquatic flora throughout the study period (Table 1) along with higher Secchi depth visibility (Fig. 1 e) compared to pond 206 except during the period of heavy rains (August to October). During this period, because of heavy rainfall, there could be an increase in clay turbidity due to runoff, which may have adversely affected Secchi disk readings. Thus, the direct effect of plants on Secchi disk visibility is more pronounced during the summer and winter months rather than during the rains. Scheffer [3] also observed vegetation related increase in transparency in shallow lakes.

The seasonal variation in DO, as evident in this study, has also been reported for other tropical [16, 18] and temperate regions [20]. In both ponds, there was a significant reduction in DO (Fig. 2a, b) during the monsoon months of August and September. Plants are known to affect DO condition of the waters as well [21, 22]. The rate of photosynthesis and oxygen production being highly dependent on light [23], cloudy days and periods of heavy rain could be the cause of oxygen depletion in the ponds. Diurnal variations of DO have also been reported to be large [24] in certain highly productive tropical and subtropical ponds with maximum values in the afternoon and minimum at sunrise [16, 25]. On a vertical scale, oxygen is often reported to decrease with depth [26] as was also found in our study for both ponds. This could

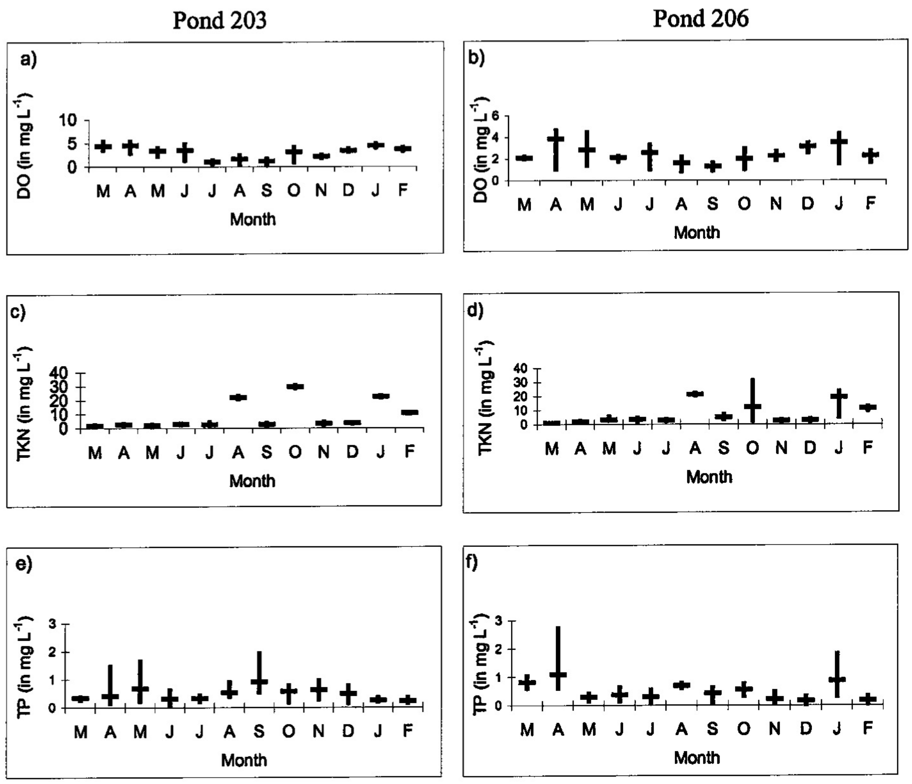

Fig. 2: Variability in the monthly range (|) and average (−) values of dissolved oxygen (DO), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) of two ponds.

Variabilität der monatlichen Spannweiten und Mittelwerte für die Konzentrationen von Sauerstoff, N_{total} und P_{total} der beiden Teiche.

be a good indicator of productivity implying that while photosynthetic activity predominated on the surface, the water at the bottom was highly reactive in terms of decomposition. In tropical systems, the annual temperature changes being small, the nearly uniform photoperiod enables practically continuous biological production.

From Table 2 it can be seen that both nitrogen and phosphorus had significant month effect, the seasonal variability in both ponds being more for phosphorus than for nitrogen (Fig. 2c–f). Sreenivasan [16] reported marked seasonal variation in nitrogen concentrations ranging from 1.03 to 7.60 mg L^{-1} in a one-year study of three tropical ponds. The values are quite similar to those found in this study with the few exceptions in August 1999, October 1999, and January 2000 (Fig. 2c, d). The high total Kjeldahl nitrogen content in both ponds during August and October 1999 could possibly be due to an increase in free ammonia content in pond waters following rainfall as has been reported by Munawar [27]. In the year 1999, an annual rainfall of 265.3 cm was the highest recorded for gangetic West Bengal in the last ten years. The low dissolved oxygen concentration of the water during the monsoons probably accelerates the activity of anaerobic bacteria, which break the nitrogenous organic matter into ammonia. However, the low total Kjeldahl nitrogen value during the month of September coinciding with season's highest rainfall (Fig. 1a), may be due to the dilution effect of rainwater. Thereafter, a high nitrogen value was also noted in January 2000 when the rainfall effect had completely died out. This could probably be the result of washing off nitrogenous fertilizers from the nursery during this time. Generally, a gradual increase in species number was also noticed in both ponds (Table 1) during the second half of the study period (August 1999 to February 2000) which was probably the effect of nitrogen enrichment.

The values of phosphorus for both ponds in this study were, however, higher than that found for other tropical ponds [28, 29]. Maximum difference in phosphorus concentration between two depths was observed in the month of April (summer) i.e., 1.29 mg L^{-1} for pond 203 and 1.64 mg L^{-1} for pond 206, which could be due to high rate of microbial decomposition of detritus at warm temperatures (30 to 32 °C). The depth effect for nitrogen and phosphorus was, however, not significant contrary to reports by Barbosa and Tundisi [13]. They reported marked differences in depth-diel profiles of major ions during day and night periods although variations were much less at the same depth. On a regional scale, temperate lakes are reported to have lower phosphorus concentrations [30] compared to tropical ones.

In tropical waters, seasonal changes are usually the result of wet and dry periods, rainfall playing a crucial role in renewing water and bringing in nutrients from the watershed.

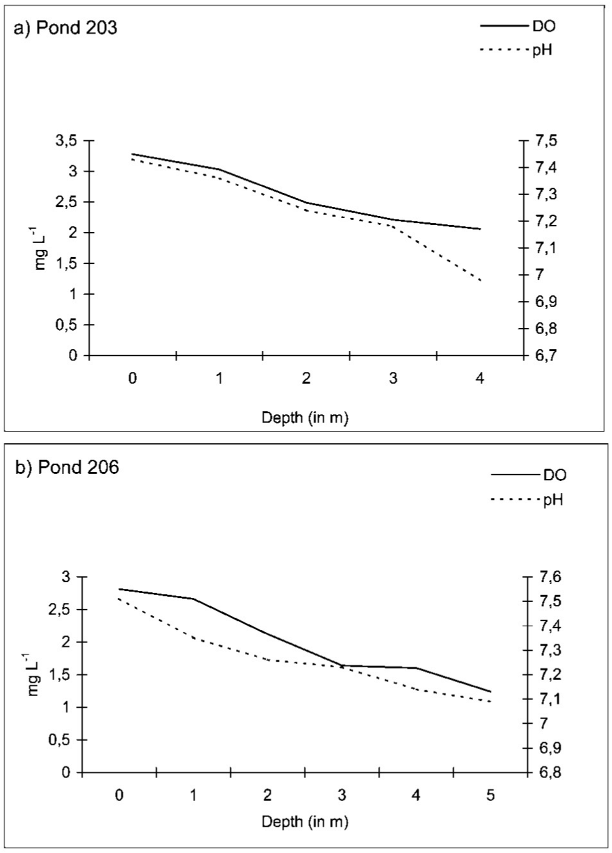

Fig. 3: Depth profile (pooled over all months) of dissolved oxygen (DO) and pH of two ponds.

Tiefenprofile (summiert über alle Monate) der Sauerstoffkonzentration und des pH-Wertes beider Teiche.

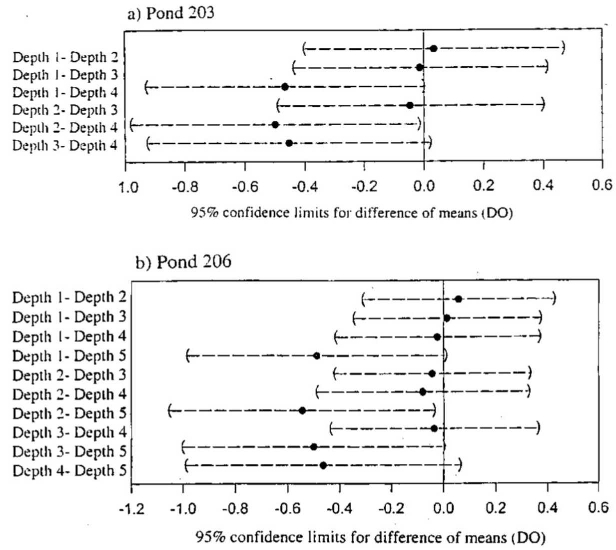

Fig. 4: Pairwise comparison of dissolved oxygen (DO) at different depths in two ponds.

Paarweiser Vergleich der Sauerstoffkonzentration in unterschiedlichen Tiefen beider Teiche.

In this study, the period between August to October 1999 (with an average rainfall above 400 mm (Fig. 1 a) was found to have a pronounced effect on most water quality parameters. For both ponds, a reduction in DO, pH, and conductivity values along with sudden spurts in nitrogen was observed during this period. For Secchi disk visibility, while pond 203 showed minimum values, a steady increase in values was seen in pond 206. Seasonality of rainfall in the tropics should, therefore, be considered to be a major environmental factor that regulate aquatic ecosystem processes and needs further study.

4.2 Impact on water quality monitoring

This study mainly focussed on the month, location, and depth effects on sampling procedures for a reliable estimate of important variables so that proper assessment of water quality of tropical ponds can be made. It did not consider diel fluctuations of the variables, many of which are reported to be large [16, 25], and hence the data reported here may not reflect a general pattern for tropical waterbodies.

A significant month effect for all water quality parameters, as can be seen from Table 2, demonstrated a high intra-annual variability. Thus, for representative annual mean water quality data, a high annual sampling frequency would be desirable. For routine monitoring, DO concentration can be monitored once in each season (summer, rainy, and winter) for a reasonable estimate with special attention during the monsoon months since a significant reduction was observed in DO values (Fig. 2a, b) during this time in both ponds. DO also exhibited a depth effect signifying depth sampling is essential where DO happens to be an important variable of study like in case of aquaculture ponds. A significant difference between the topmost and the bottommost depth at the deepest point (Fig. 4a, b) clearly suggested that sampling should be conducted both from the top as well as from the bottom depths.

Since the clarity of a natural body of water is a major determinant of the condition and productivity of that system, a measure of clarity would be a very useful parameter in management of freshwater ecosystems. Thus, transparency of water could be routinely monitored by the local people using a Secchi disk, an easy to use device, for a regular check on the water quality of ponds. Along with monthly fluctuations,

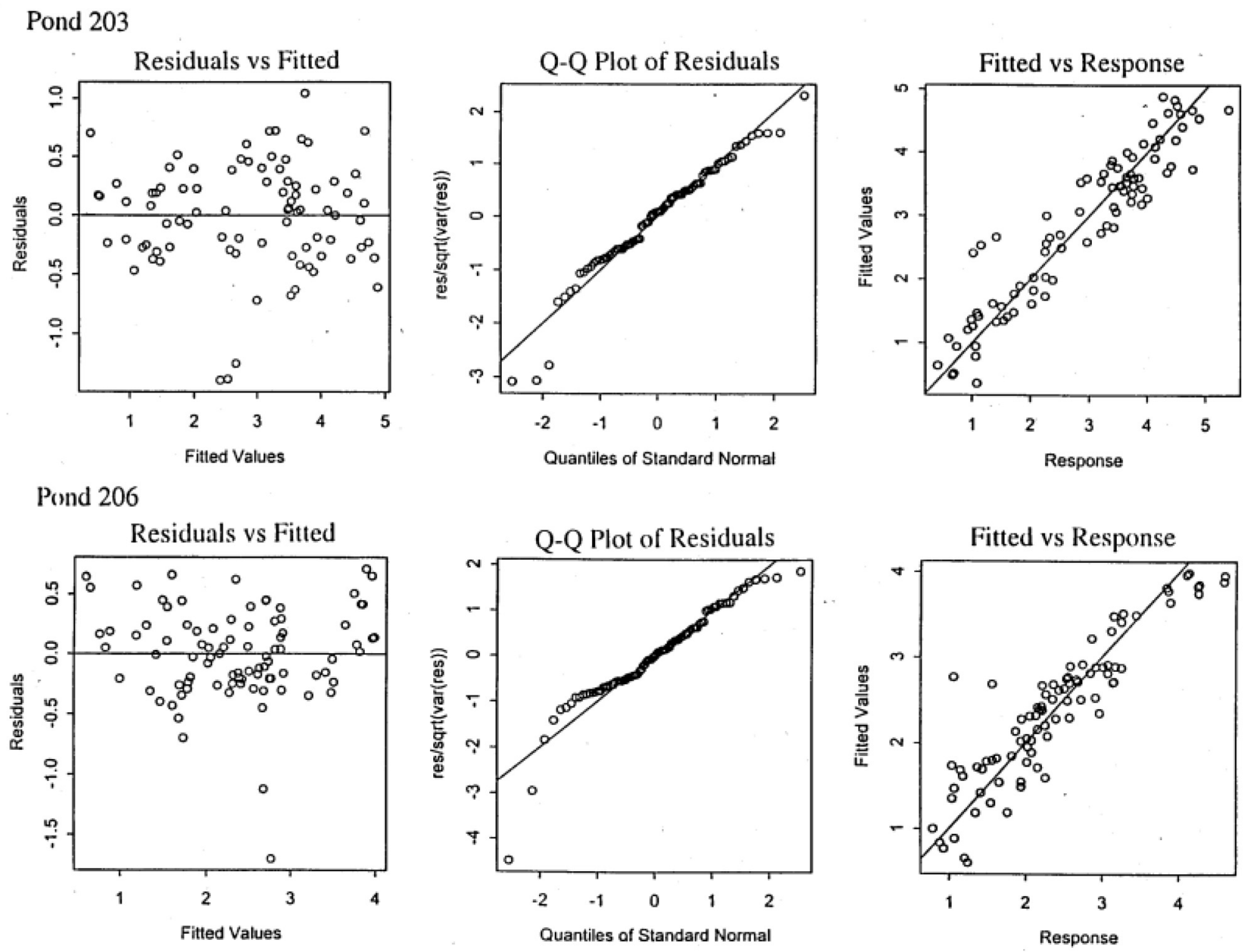

Fig. 5: Graphical diagnostics for the model assumption for analysis of dissolved oxygen in two ponds.

Graphische Diagnose der Modellvoraussetzung zur Analyse der Sauerstoffkonzentration in beiden Teichen.

Secchi depth exhibited a significant location effect in pond 203. Hence, Secchi depth should be monitored from more than one site in ponds with a rich aquatic flora while only one location would be sufficient for ponds with no or few aquatic plants. Secchi depth readings should be taken routinely during summer and winter months while it can be avoided during the rainy season because of the negative effect of clay turbidity, which is a purely temporary and seasonal effect. Moreover, anthropogenic use of ponds is also comparatively less during this season when rain itself is a source of water.

For nitrogen and phosphorus, the absence of any location and depth effect in this study signifies that sampling could be done from any point to be representative of the whole pond if the water were only intended for nutrient analysis. This would greatly reduce the cost and time of sampling which are often the main constrains for water quality monitoring in tropical countries. Special attention should be given to sampling during the monsoons in view of the high nitrogen concentration observed in both ponds during this time.

For studies on macrophytes, rainy season is very important since diversity increases as a result of which competition between species for nutrients also increases.

5 Conclusions

The factors affecting water quality of the two ponds are diverse and complex. Marked monthly differences found in major water quality variables in the two ponds probably reflects that tropical systems are more sensitive to changes in nutrient supply and hence the importance of continuous monitoring and management programs. Selection of efficient sampling schemes would effectively minimize the time and effort needed for continuous monitoring which is essential in tropical countries where the rate of pollution is also higher. Studies on diurnal variations of important water quality parameters in tropical water bodies should also be done in view of the large fluctuations that have been reported.

Acknowledgements

We are grateful to Prof. Anup Dewanji, Applied Statistics Unit, for his help with the statistical analysis. Thanks are due to L. B. Magranti, G. Bhaumik, M. Saha, and B. Behara of Plant Chemistry Unit, for their sincere assistance during the fieldwork.

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[Received: 14 July 2003; accepted: 29 January 2004]