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Full Length Research Paper

Physicochemical gradients and *in situ* yields in pelagial primary production of the middle reaches of Imo River in Etche, South-eastern Nigeria

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We investigated seasonal variations and influences of some physicochemical attributes of the Southeastern-Nigeria Imo River on the primary productivity at its middle course between March 2007 and February 2008. *In situ* determinations of water temperature, pH, turbidity, and dissolved oxygen (DO) were made with HORIBA U-10 water quality checker at 7 sampling locations and water samples collected in 500 mL sterile containers and transported to the laboratory in iced-coolers. The light and dark bottle technique for the measurement of primary production was utilized and gross and net primary production (GPP and NPP) as well as community respiration (CR) computed. In the laboratory, nitrate, sulphate and phosphate concentrations were determined according to standard methods by the cadmium reduction, barium chloride (turbidometric), and ascorbic acid methods, respectively. Correlation coefficient (r) was used to determine the influence of the physicochemical variables on primary production while studentized t-test was used to ascertain significant differences between seasons. DO varied from 4.50 to 8.81 (6.96 ± 0.14) mgL^{-1}, turbidity from 11.0 to 279.00 (96.7 ± 9.3) NTU, nitrate from 0.10 to 1.35 (0.53 ± 0.04) mgL^{-1}, and sulphate from 0.90-8.10 (4.35 ± 0.25) mgL^{-1}. Sulphate varied significantly at P<0.05, while turbidity showed high numerical variation only. Mean GPP, NPP, and CR were higher in the dry than wet season, even as there was no significant seasonal variation [$tcal_{(0.30)}<t_{crit(2.13)}$] at P<0.05. Annual yields were 10.9, 5.4, and 2.7 mgO$_2$L^{-1}d^{-1} for GPP, NPP and CR, respectively. The dry season months (January and February) yielded highest mean GPPs of 2.5 and 2.6 mgO$_2$L^{-1}d^{-1}, respectively. pH exerted significant positive influences on GPP, NPP, and CR at P<0.01. The observed oligotrophic production was attributed to low water nutrient level (most probably resulting from depletions through benthal excavations during sand mining) and high turbidity (due to re-suspension of benthal sediments), which limits solar radiation necessary for autotrophic production. The higher productivity recorded in the dry season was due to more concentration of nutrients (nitrate) and lowered turbidity.

Key words: Etche, Imo River, Niger Delta, sand mining, autotrophs.

INTRODUCTION

Primary production is the manufacture of organic compounds from atmospheric or aquatic carbon (IV) oxide, principally through the process of photosynthesis, with chemosynthesis being much less important (Global Change, 2008). All life forms on earth are directly or indirectly dependent on primary production and the organisms responsible for it are the primary producers or autotrophs, which form the base of the trophic chain. In terrestrial ecosystems, those organisms are mainly plants, while in aquatic ecosystems algae are primarily responsible (Kaufmann and Claveland, 2008; Simmons et al., 2004). Primary production is distinguished as either net or gross, the former accounts for losses to processes such as cellular respiration, while the latter is not.

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At the fundamental level, primary production is the capture of energy in the form of electromagnetic radiation and its conversion to, and storage as, chemical energy by living organisms. The main source of this energy is the sun. A very tiny fraction of primary production is driven by organisms utilizing the chemical energy of inorganic molecules. The primary source of variability of primary production is light (solar energy), and the secondary source nutrients (Graneli and Heraldsson, 1993; Guildford and Hecky, 2000; Simmons et al., 2004). Temperature (Neori and Holm-Hansen, 1982; Tilzer and Dubinsky, 1987) and seasonal variations in light penetration (Vaillancourt et al., 2003) also largely determine the distribution of phytoplankton productivity.

Irrespective of the source of this energy, it is used to synthesize complex organic molecules from simpler inorganic compounds such as carbon (IV) oxide and water according to the following equations (Global Change, 2008):

$$CO_2 + H_2O \xrightarrow{\text{Light}} CH_2O + O_2 \quad \text{(Photosynthesis)}$$

$$CO_2 + O_2 + 4H_2S \longrightarrow CH_2O + 4S + 3H_2O$$
(One form of chemosynthesis)

In both cases, the end point is reduced carbohydrate (CH_2O), typically molecules such as glucose or other sugars. These relatively simple molecules may be then used to synthesis further, more complicated molecules, including protein, complex carbohydrates, lipids, and nucleic acids, or be respired to perform work.

Consumption of primary producers by heterotrophs such as animals then transfers these organic molecules (and the energy stored within them) up the food chain, thus, fuelling all of the earth's living systems.

In Nigeria for example, primary productivity studies are not new, though there exist paucity of documented literature on it. Of the few available ones are the works of Imevbore et al. (1972), Karlman (1973), Adeniji (1979; 1980; 1990) and Ikenweiwe and Otubusin (2005). Of these, the most comprehensive and earliest one on pelagial primary productivity in Nigerian Inland water (Kainji Lake) appears to be the work of Karlman (1973) based on studies he made in 1971/72.

However, there exist no documented works on this aspect of hydrobiology in the Imo River, even as it is one of the major inland freshwater systems traversing the hub of the hydrocarbon rich Niger Delta region of Nigeria, especially at its middle and lower reaches. This study therefore presents findings from seasonal variation and influences of some physicochemical characteristics of the river on primary production, utilizing simple traditional approach that is applicable in environments with sparse facilities.

It attempts to achieve this aim through the following objectives:

1. Measurement of some climatic variables of the study area;
2. Determination of some physicochemical variables of the river;
3. Measurement of its gross and net primary production (GPP and NPP), as well as community respiration (CR);
4. Determination of influences of physicochemical variables on primary production;
5. Determination of seasonal variation in primary production of the river.

MATERIALS AND METHODS

Study area

Etche, a south-eastern ethnic nation in the tropical rainforest region of Nigeria is located between longitude 06° 05' and 07° 14' E and latitude 05° 08' and 04° 45' N (Figure 1). Annual rainfall is between 2250 and over 2500 mm, with a wet season that usually last from March-November (SPDC, 1998). Atmospheric temperature is between 24-31°C, with high relative humidities of up to 90% during the wet season. The Imo River is one of the three inland freshwater systems in the area, it empties independently into the Atlantic Ocean, after coursing through Oyigbo, Khana, Opobo/Nkoro, and Andoni. In Etche, the river is alluvial (Sikoki and Zabbey, 2006) and experiences flooding usually between August and November, marking the peak of the wet season.

The major activity of inhabitants of the area is farming, though some also engage in petty trading, palm wine tapping, fishing, hunting and sand mining in this river.

Weather data

The prevalent mean monthly ambient temperature and relative humidity of the study area were obtained from the Hong Kong Observatory page http://www.hko.gov.hk/wxinfo/climat and the Ecoserve Publishers page http://www.ecoservepublishers.org/article.

Sampling strategy

Sampling was made monthly for a year, covering the wet and dry seasons at 7 sampling locations.

Field sampling

Water temperature, dissolved oxygen (DO), turbidity, and pH were measured *in situ* with HORIBA U-10 Water Quality Checker. Water samples for laboratory analysis were collected with 500 mL sterile containers and transported to the laboratory, about 20 km away, as soon as possible in iced-coolers.

Laboratory analysis

Nitrate, phosphate, and sulphate were determined by standard methods as provided by APHA (1998). Nitrate was determined by the cadmium reduction method, sulphate was determined by the barium chloride (turbidometric) method, while phosphate was determined by the ascorbic acid method (APHA, 1998).

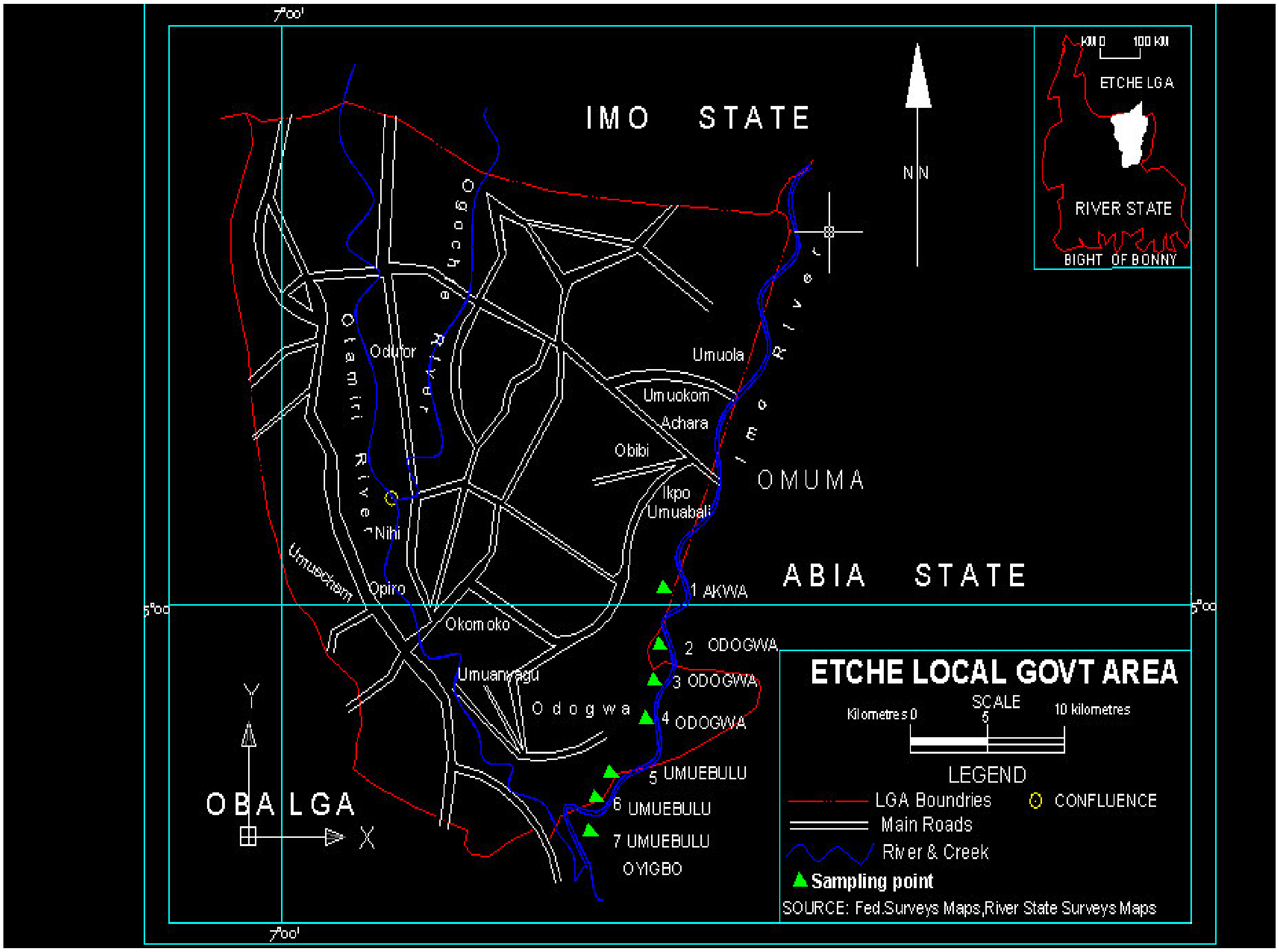

Figure 1. Map of Etche local government area showing the sampling locations.

Primary production studies

Three identical transparent 1-litre bottles were filled with the river water and stoppered while still submerged. The first bottle was analyzed immediately for oxygen and used to determine the initial O_2 concentration, while the other two bottles were suspended in the pelagial water zones where the water had been taken, with the aid of a rope; one covered with black polythene and the other not covered (that is, transparent). The setup was allowed to stand for 4 h in sunny afternoon hours (Ikenweiwe and Otubusin, 2005). Immediately after the incubation period, the bottles were harvested and the O_2 concentrations in them measured with a HORIBA U-10 Water Quality Checker. This experimentation was done in replicates and the average recorded.

As photosynthesis would not have taken place in the dark bottle, it provided a measure of respiration while the light bottle that permitted both photosynthesis and respiration provided a measure of net photosynthesis.

Calculation

$$GPP\ (mgO_2L^{-1}d^{-1}) = NPP\ (mgO_2L^{-1}d^{-1}) + CR\ (mgO_2L^{-1}d^{-1})$$

Where; GPP is gross primary production (photosynthesis), NPP is net primary production (photosynthesis), and CR, community respiration (Simmons et al., 2004).

Statistical analysis

The Pearson product moment correlation coefficient (**r**) was employed to determine the influence of the physicochemical variables on primary production, while the studentized t-test was used to determine significant seasonal variations in the physicochemical and productivity variables.

RESULTS

Physicochemical characteristics

Figure 2 shows that surface water temperature closely followed atmospheric temperature variation during the study period. Maximum atmospheric temperature was highest in February 2007 and 2008 (33.4 and 33.5ºC respectively) and least in July and August 2007 (28.7ºC each). Lower atmospheric temperatures (28.7 to 30.0ºC) were recorded during the wet season months of June to

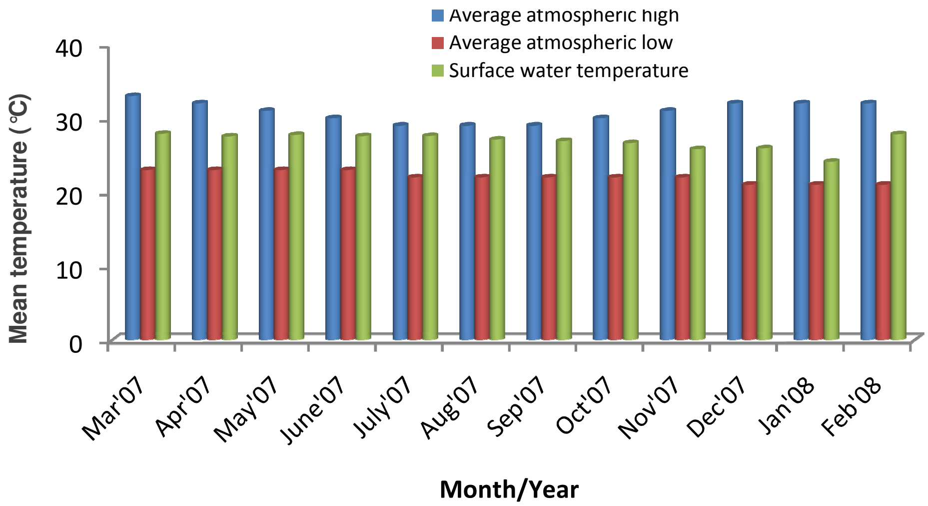

Figure 2. Monthly variation in mean atmospheric and water temperature in Imo River.

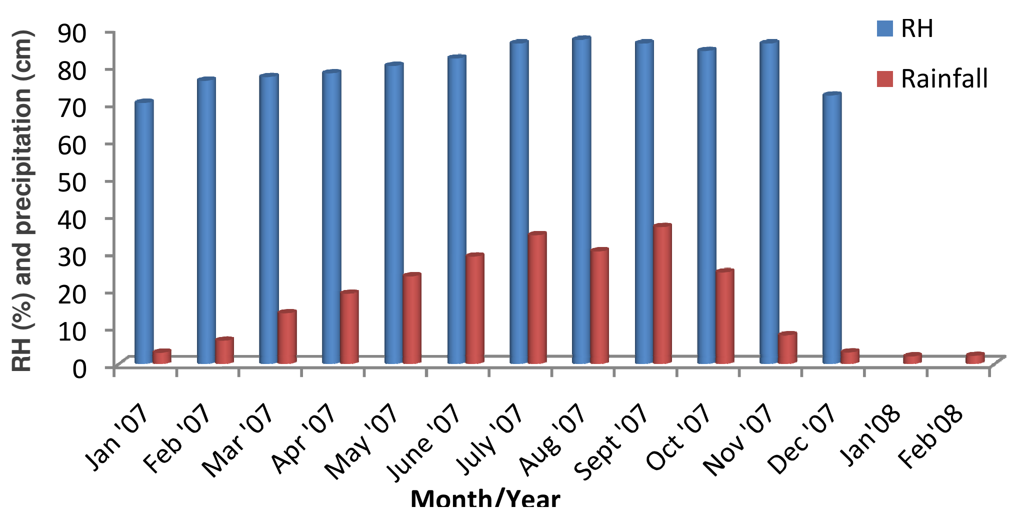

Figure 3. Monthly variation in average of precipitation and relative humidity.

July 2007 than in the dry season months of November-February (31.2 to 33.5ºC). Highest humidities of 80 to 86% were recorded during the wet season months. Figure 3 shows monthly precipitation and relative humidity. A relatively humid weather therefore prevailed during the greater part of the year. High precipitation of 13.55 to 36.71 cm was recorded during the peak rainy months of March-October while values as low as 1.95 to 2.10 cm was recorded in the dry season months of January-February.

Wide variations were observed in DO (4.50 to 8.81 mgL^{-1}), turbidity (11.0 to 279.00) NTU, nitrate (0.10 to 1.35 mgL^{-1}), and sulphate (0.90 to 8.10 mgL^{-1}), with means of 6.96 (± 0.14), 96.7 (± 9.3), 0.53 (± 0.04), and 4.35 (± 0.25) respectively (Table 1). Of the physicochemical characteristics measured, only sulphate showed significant seasonal variation[$tcal_{(2.32)}>t_{crit(2.23)}$] at the probability level, P<0.05 (that is, 95% confidence limit (Table 2).

Primary production studies

Generally, GPP and NPP ranged from 0.10 to 11.3 (0.9 ± 0.2) and 0.10 to 1.00 (0.40 ± 0.03) $mgO_2L^{-1}d^{-1}$ respectively. CR ranged from 0.02 to 0.50 (0.23 ± 0.02) $mgO_2L^{-1}d^{-1}$. Production peaked in the dry season months of January and February and at the onset of wet season in April, but was least at the peak of the wet season from August to October (Figure 4). Table 3 shows that the dry season months recorded higher mean GPP (1.90 ±0.6), NPP (0.60 ± 0.1) and CR (0.30 ± 0.1) $mgO_2L^{-1}d^{-1}$ yields than the wet season months. Annual GPP, NPP and CR were estimated at 10.90, 5.40 and 2.70 $mgO_2L^{-1}d^{-1}$

Table 1. Descriptive statistics of the physicochemical characteristics of Imo River.

Parameter	Range (mean ± SE)
Water temperature (°C)	24.00-28.10 (26.89 ± 0.12)
pH	6.00-6.70 (6.40 ± 0.02)
DO (mg/l)	4.50-8.81 (6.96 ± 0.14)
Turbidity (NTU)	11.0-279.0 (96.7 ± 9.3)
Nitrate (mgL^{-1})	0.10-1.35 (0.53 ± 0.04)
Phosphate (mgL^{-1})	0.07-0.23 (0.13 ± 0.01)
Sulphate (mgL^{-1})	0.90-8.10 (4.35 ± 0.25)

SE = standard error.

Table 2. Mean seasonal variation in physicochemical characteristics of Imo River.

Parameter	Season		Calculated	t-critical
	Wet	Dry	t –value	
Water temperature (°C)	27.2	25.9	1.24	
pH	6.4	6.5	1.46	
DO (mg/l)	7.21	6.23	1.16	2.23
Turbidity (NTU)	112.7	48.6	1.68	
NO_3^- (mg/l)	0.53	0.55	0.10	
PO_4^{2-} (mg/l)	0.13	0.11	1.12	
SO_4^{2-} (mg/l)	4.99	2.46	2.32*	

*=significant at P<0.05.

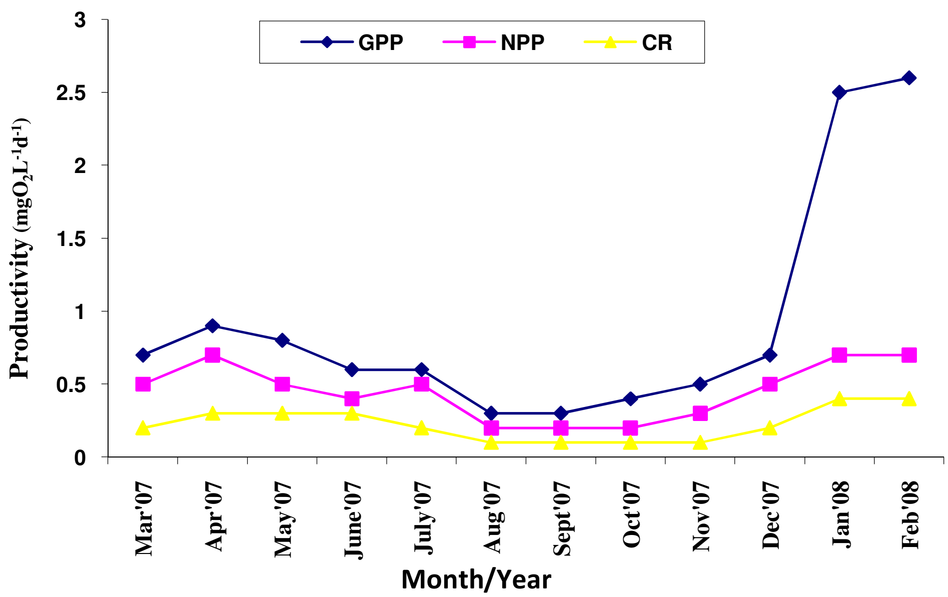

Figure 4. Monthly variation in primary production of Imo River in ELGA.

respectively. However, the student's t-test value of 0.30 indicates that there was no significant seasonal difference in primary production variables during the study period at P<0.05. At the 95% confidence limit, GPP showed the highest mean seasonal difference of 0.746, while CR showed the least mean difference of 0.257.

Table 3. Seasonal variation in primary production of Imo River.

Primary production	Season		Annual production ($mgO_2L^{-1}yr^{-1}$)	Mean seasonal difference	Calculated t-value
	Wet	Dry			
ΣGPP ($mgO_2L^{-1}d^{-1}$)	5.10	5.80 1.90(±0.6)	10.9	0.746	
Mean GPP ($mgO_2L^{-1}d^{-1}$)	0.60(±0.3)				
ΣNPP ($mgO_2L^{-1}d^{-1}$)	3.50	1.90	5.4	0.488	0.30
Mean NPP ($mgO_2L^{-1}d^{-1}$)	0.40(±0.2)	0.60(±0.1)			
ΣCR ($mgO_2L^{-1}d^{-1}$)	1.70	1.00	2.7	0.257	
Mean CR ($mgO_2L^{-1}d^{-1}$	0.20(±0.1)	0.30(±0.1)			

Σ= total, t_{crit}-= 2.13 (P<0.05).

Table 4. Correlations (r) between the physicochemical characteristics and primary production.

Parameter	Wtemp	pH	DO	Turb	NO_3^-	PO_4^{2-}	SO_4^{2-}
GPP	-0.092	0.850**	-0.803**	-0.845**	-0.553*	-0.056	-0.832**
NPP	-0.095	0.861**	-0.802**	-0.845**	-0.561*	-0.101	-0.824**
CR	-0.098	0.878**	-0.802**	-0.845**	-0.568*	-0.106	-0.814**

*=significant at P<0.05, **=significant at P<0.01.

Physicochemical characteristics and primary production

At P<0.05, GPP, NPP and CR correlated negatively with nitrate and at P<0.01, they correlated positively with pH. However, at P<0.01, they correlated negatively with DO, turbidity, and sulphate (Table 4).

DISCUSSION

The primary production of the present study was low when compared with the works of earlier researchers in Nigerian inland waters (Samaan, 1971; Mbagwu and Adeniji, 1994; Ikenweiwe and Otubusin, 2005). However, its yield was higher than mean values recorded by Adeniji (1980) in Bakolori Lake, Sokoto State and by Adeniji (1990) in Asa Lake, Ilorin, all in Nigeria, as well as values recorded by Simmons et al. (2004) in the US Appalachian coal region. This low productivity could be due to the observed low nutrient levels (especially nitrate and phosphate) and high turbidity, which exert limiting influences on photosynthetic optimum of the autotrophs (Global Change, 2008). Ongoing commercial sand mining in the river most probably has led to depletion of nutrient stores, especially in the benthal regions of the river. Guildford and Hecky (2000) had also identified phosphate as the nutrient that most commonly limits productivity in freshwater systems. In-stream sand mining activity also re-suspends particulate matter in water column, thus constituting increased turbidity (Adams, 2003) and subsequent low phytoplankton abundance and productivity. The significant influences of pH and DO on productivity variables confirm their vital roles in ecosystems processes. Studies have shown that some pollutants (e.g. heavy metals) have greater toxicity towards algae at circumneutral pH (Hargreaves and Whitton, 1976; Campbell and Stokes, 1985; Bortnikova et al., 2001) such as in this study. The observed optimal productivity in the dry season months of January and February could be due to significantly reduced water volumes (non-flooding season), as well as increased sunlight duration (Marra, 2002). Adeniji (1980) also observed that primary productivity decreased with water volumes.

Generally, the mean higher production recorded in the dry than wet season was probably due to corresponding slight increase in nitrate, as well as reduced turbidity. Graneli and Heraldsson (1993), Guildford and Hecky (2000) and Simmons et al. (2004) have also observed the positive influence of nutrients on primary production. Accordingly, more yield in mean NPP resulted. However, further increases in concentrations of the nutrients (especially nitrate and sulphate) appeared to inhibit production going by correlation results. The cumulatively higher CR in the wet season could either be due to the contributions of the longer wet season months of the year alone or in association with the more DO that was available for autotrophs respiration in the season, even as there was no significant difference in yields between the seasons. The significant effects of pH on production confirm its vital role in aquatic ecosystems processes. Studies have shown that some pollutants (e.g. heavy metals) have greater toxicity towards algae at circumneutral pH (Hargreaves and Whitton, 1976; Campbell and Stokes, 1985; Bortnikova et al., 2001) as seen in this study.

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