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In situ yields in primary productivity of sand mine ponds of the Otamiri River in a southeastern city of Nigeria

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A B S T R A C T

In situ yields in primary productivity of sand mine ponds of the Otamiri River in Owerri, southeastern Nigeria was investigated during the wet and dry seasons of 2012/2013. Eighteen sampling points designated as WC 1-WC 18 and located within 9 artificial ponds where active sand mining was ongoing and 9 ponds where it had ceased were studied. In situ measurements were made for surface water temperature, dissolved oxygen (DO), pH, conductivity, salinity and total dissolved solids (TDS) using standard methods. Measurements were also made of other physicochemical variables. The single factor ANOVA, means plots, Principal Components Analysis (PCA), Pearson correlation (r) and student's t-test were used to analyse data. Gross and net primary productivity (GPP & NPP) as well as community respiration (CR) varied as follows: 0.1800-0.6550 (0.3121 ± 0.0377), 0.1013-0.6000 (0.2761 ± 0.0382) and 0.0100-0.0810 (0.03363 ± 0.0055) $mgCL^{-1}d^{-1}$ respectively. There was significant spatial heterogeneity in mean variance of primary productivity [F(169.80)>Fcrit(3.93)] at P<0.05, with the actively sand mined pond showing higher productivity, accompanied with higher nutrients (PO_4^{2-}, NO_3^-, SO_4^{2-}) concentrations and slightly higher turbidities than the non-mined pond. Productivities also differed markedly (Sig. t=0.000) between the seasons, with higher dry than wet season yields. The first four PCs formed the extraction solution in the original 16 physicochemical parameters measured with a cumulative 95% variability contribution. The components had high loadings for the nutrients and turbidity factors. GPP correlated with PO42- (r=0.976), NO3- (r=0.955) and turbidity (r=-0.946) at P<0.01. Active sand mining appeared to enhance primary productivity in the mine pond through re-suspension and elevation of growth nutrients in water column, even as this was associated with slightly increasing turbidities.

1. Introduction

For thousands of years, sand and gravel have been used in the construction of roads and buildings. Sequel to this, Tamuno (2005) asserted that dredging and mining has both detrimental and beneficial effects. He outlined the benefits of inland dredging, [which according to Bray, et al., (1998) are most often localized] to include improved navigational channels, land reclamation, socio-economic development, flood mitigation, and beneficial usage of dredged materials.

On the contrary, alterations of hydrological regimes, loss of wetland and floodplains, sediment suspension and increased turbidity, impacts on flora and fauna, and impacts on livelihoods have been recognized as the localized adverse impacts of dredging and mining. He further stated that the duration of biota re-adjustment is longer than that of physicochemical attributes of surface water in dredged areas.

Other studies have also confirmed the negative effects of sand dredging and mining on some World's Delta ecosystems. For example, channel dredging has been identified as one of the factors that have resulted in the environmental deterioration of Danube Delta (Pringle et al. 1993), the Okavango Delta (Ellery and McCarthy, 1994), and the Niger Delta (Abam, 2001; Ohimain, 2004; Ohimain, et al. 2005; Ogbuagu et al., 2011). Today, the demand for sand and gravel continues to increase to such an extent that there is need for mining operators in conjunction with environmentalists to ensure that sand mining is conducted in a responsible manner. The Otamiri River which rises from Egbu in Imo State, Nigeria courses through Owerri, the capital city, onto the neighbouring Rivers State where it empties into the Imo River that subsequently runs into the Atlantic Ocean. The river provides domestic source of water and serves for fisheries. Due to mounting demands for sand and gravel for building and other construction works occasioned by increasing urbanization and infrastructural development needs, the river has been subjected to intense sand mining by local artisans, as well as small and medium sized operators in recent years. Over time, artificial ponds have become relics of the riverside in-bank mining or excavation activities. While some of these sites are still actively mined, others have been abandoned after the sand and gravel deposits were exhausted. These sites vary from lentic to semi-lotic flow rates, thus, creating more residency time for biotic and abiotic interactions in the habitats. This makes them good breeding grounds for aquatic biota. This environmental perturbation coincides with complaints by local fishermen of reduced fish catches; an observation they have attributed to natural occurrences related to apocalyptic beliefs. Since it has been reported that sand mining could induce negative impacts on aquatic biota, including reduction in their abundances, diversity and regenerative potentials, depletion in abundances of the auto-phototrophic biota such as green algae and bacteria could result to impaired aquatic primary productivity in the euphotic zones of the water column. Though sand mining has not continued unabated along the stretch of this river, regulatory intervention nor scientific investigations have been applied for a better understanding of the inductions created by this anthropogenic activity. This research was an attempt to bridge the gap, through the investigation of possible effects of sand mining on in situ primary productivity of mine ponds of the river. It undertook this using spatial approach to investigations of possible inductions on driver physicochemical regulators.

2. Materials and methods

2.1. Study Area

Owerri, the southeastern city of Imo State, Nigeria lies within latitude 05° 29´ 06s and longitude 07° 02´ 06s (Figure 1). The city experiences a longer wet season from April to November than dry season (Victor et al., 2011).

Mean daily maximum temperature is between 28 and 35 °C, while daily minimum values range between 19 and 24 °C, with average humidity of up to 80%. Semi-deciduous forest vegetation that had been altered by agricultural and other anthropogenic activities dominates the area (Onweremadu et al., 2008) and the dominant top-soil is moderately humus in composition. The Otamiri River, one of the two major rivers that traverse the city provides domestic source of water and serves for fisheries as well as artisanal sand mining by local operators. The segment of the river studied covered Ihiagwa/Umuchima, the Federal University of Technology, Owerri (FUTO) and Eziobodo, spanning about 5km in the middle reaches of the river.

2.2. Field sampling

2.2.1. Sampling locations

A total of 18 sampling points, designated as WC 1-WC 18; with WC 1-WC 9 sited in artificial derelict (about 7 months old) sand mine ponds and WC 10-WC 18 in ponds under intense active in-stream mining, were established about 50m apart in a total of 6 river-side ponds at the middle course of the river. Replicate sampling were made monthly in the wet (September-November, 2012) and dry seasons (December, 2012-February, 2013).

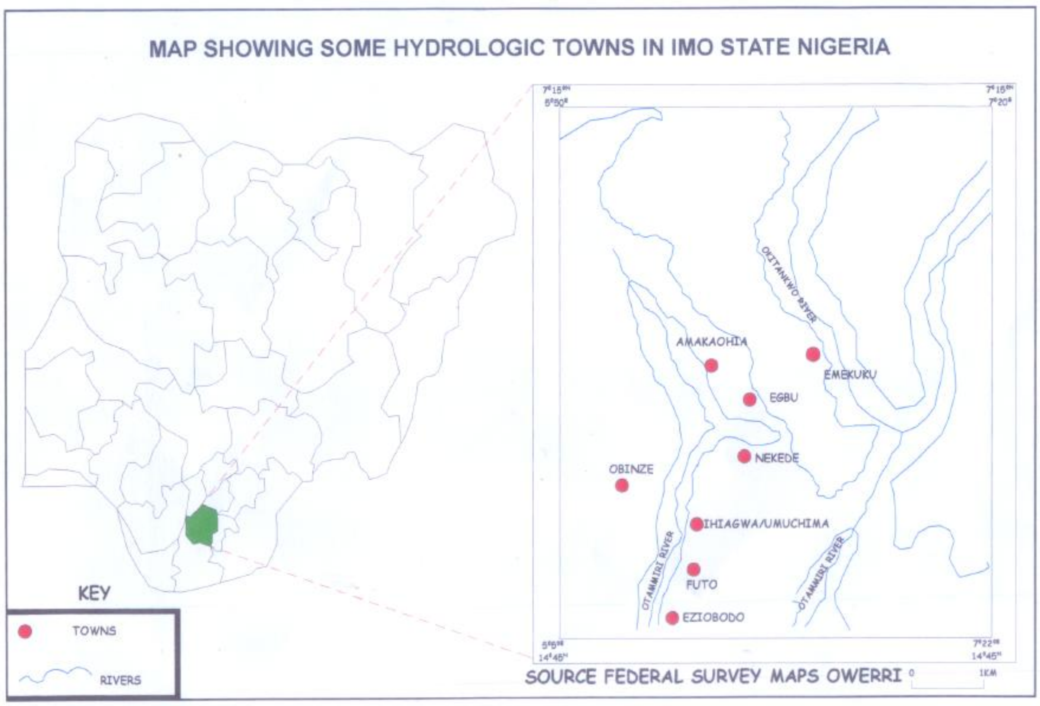

Fig. 1. Location map of Nigeria showing Otamiri River in Owerri, Imo State.

2.2.2. In situ measurements

In situ determinations for water temperature, dissolved oxygen (DO), pH, conductivity, salinity and total dissolved solids (TDS) was made with a pre-calibrated HANNA HI 9828 pH/ORP/EC/DO meter in each pond.

2.3. Primary productivity measurements

The light and dark bottle incubation method originally developed by Gaarder and Gran in 1927, as modified by the Global Change (2008) was utilized in the estimation of in situ primary productivity. Three identical transparent 1-litre bottles were filled with the pond water and stoppered while still submerged. The first bottle was analyzed immediately and used to determine the initial oxygen concentration. 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 (dark bottle) and the other not covered (light bottle). The setup was allowed to stand for 4 hours in a sunny afternoon (Ogbuagu and Ayoade, 2011) at each of the sampling locations. Immediately after the incubation period, the O2 concentrations in the bottles were measured in replicates. 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.

The relevant primary productivity variables were calculated as mg of O2 produced per litre of water per day using the following formula:

GPP (mgO2L-1d-1) = NPP (mgO2L-1d-1) + CR (mgO2L-1d-1)

where GPP is gross primary productivity (photosynthesis), NPP is net primary productivity (photosynthesis), and CR, community respiration (Simmons et al., 2004). The carbon equivalents of productivity variables were computed by multiplying the O2 values by 0.375 and expressed as mgCL-1d-1 (Global Change, 2008).

2.4. Laboratory analysis

Nitrate was determined by the cadmium reduction method, sulphate by the barium chloride (turbidometric) method, and phosphate by ascorbic acid method (APHA, 1998). TSS was determined according to ASTM D1888-78 method, turbidity was measured with the HACH DR 2000 Spectrophotometer, while the heavy metals were determined by the atomic absorption Spectrophotometric method.

2.5. Statistical analysis

The single factor analysis of variance (ANOVA) was used to determine variance equality in spatial yields of primary productivity while the structure of group means for the identification of variant productivity variable(s) was further made with means plots. The principal components analysis (PCA) extraction method was used to remove redundant physicochemical variables from the data file and replacing the entire data file with a smaller number of uncorrelated factor. Factor rotation was achieved with Varimax method and the magnitude of the eigenvalues and 75% (0.75) rule for variance contribution were used for factor selection (Manly, 1986). The influences of the physicochemical variables with primary productivity was established with the Pearson correlation (r), while marked seasonal partitioning in productivity was explored with the student's t-test of significance.

3. Results

3.1. Yields in primary productivity

Gross and net primary productivity (GPP & NPP) as well as community respiration (CR) showed narrow variations in this study (ranges=0.4750, 0.4987 & 0.0710 mgCL-1d-1 respectively). While GPP varied from 0.1800-0.6550 (0.3121 ± 0.0377), NPP and CR varied from 0.1013-0.6000 (0.2761 ± 0.0382) and 0.0100-0.0810 (0.0363 ± 0.0055) mgCL-1d-1 respectively.

3.2. Spatial and Seasonal variations in primary productivity

Maximum GPP of 0.6550 mgCL-1d-1 was recorded in sampling location 18 (WC 18) while minimum productivity of 0.1800 mgCL-1d-1 was recorded in WC 1 (Figure 2). The least NPP (0.1013 mgCL-1d-1) and CR (0.0100 mgCL-1d-1) were recorded in WC 1 and WC 16, while their maximum yields of 0.6000 and 0.0810 mgCL-1d-1 were recorded in WC 18 and WC 13 respectively.

The test of homogeneity in spatial mean variance of the primary productivity variables revealed significant ($p<0.05$) heterogeneity [F(169.80)>Fcrit(3.93)]. A post-hoc structure detection of group means revealed that yields in GPP & CR contributed the observed heterogeneity in WCs 2, 3, 4, 5, 8, 9, 10, 11, 12, 14, 15, 16, 17 & 18, GPP & NPP contributed this in WC 6 while GPP contributed it in WCs 7 & 13. The student's t-test in pooled productivity variables between the actively unperturbed and perturbed locations revealed significantly uncorrelated (Sig. r=0.207) homogeneity (Sig. t=0.467) at $P<0.05$.

Numerically higher dry (0.2346 ± 0.0033mgCL-1d-1) than wet season productivities (0.1711 ± 0.0025mgCL-1d-1) were obviously recorded in this study. Sequel to this, there was very high significant heterogeneity in mean productivities between the seasons (Sig. t=0.000) at $P<0.05$.

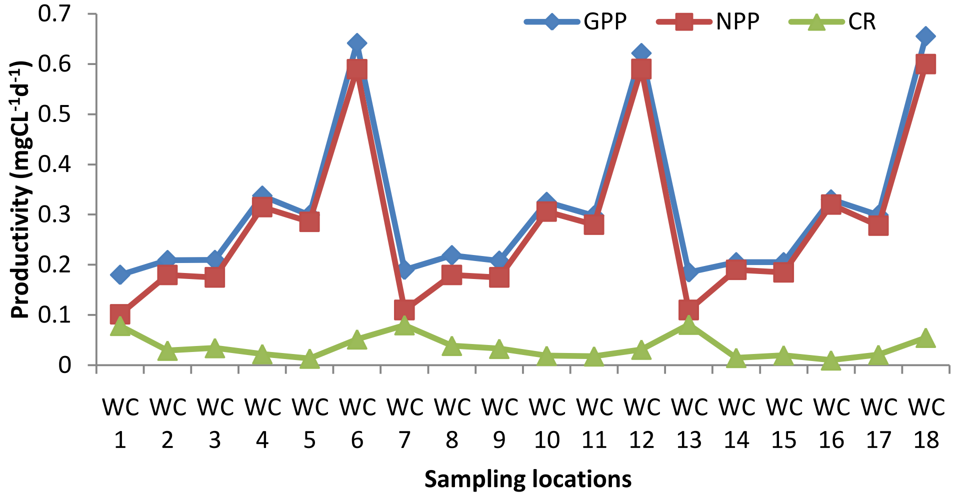

Fig. 2. Spatial variations in gross and net primary productivity and community respiration of sand mine ponds of Otamiri River.

3.3. Principal components analysis (PCA)

Of 16 physicochemical parameters measured in the water column during the study period (water temperature, dissolved oxygen, pH, electrical conductivity, salinity, total dissolved solids, sulphate, phosphate and nitrate ions, total suspended solids, turbidity and the trace metal ions- Cd, Cu, Ni, Zn and Pb) which were subjected to the PCA extraction, the first four PCs formed the extraction solution. The extracted components explained about 95% of the variability in the original variables (Table 1); a cumulative percentage of variance explained that was maintained by the rotation (Table 2).

Table 1
Total variance explained in extracted component of the physicochemical parameter in water columns of Otamiri River.

Components	Extraction sums of squared loadings		
	Total	% of variance	Cumulative %
1	7.306	45.662	45.662
2	4.888	30.553	76.215
3	1.895	11.843	88.057
4	1.120	6.997	95.054

Table 2
Rotated total variance explained of the physicochemical parameters in water columns of Otamiri River.

Components	Extraction sums of squared loadings		
	Total	% of variance	Cumulative %
1	4.574	28.588	28.588
2	4.322	27.015	55.604
3	4.227	26.419	82.022
4	2.085	13.032	95.054

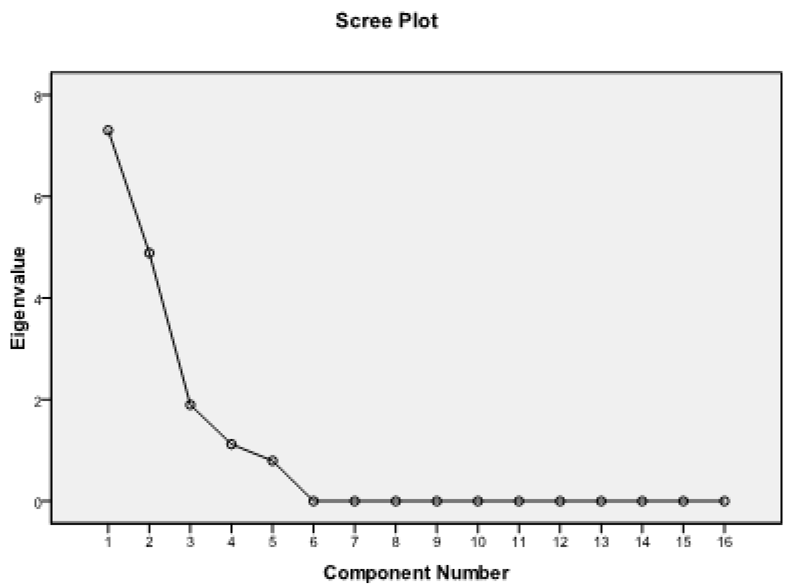

Fig. 3. Scree plot of eigenvalues of components.

The scree plot (Figure 3), representing the eigenvalues of each component in the initial solution shows the extracted components on the steep slope and the rest 12 components that contributed the meagre 5% to the solution on the shallow slope. The 1st component which was most highly correlated with Ni (0.897) had high loadings for trace elements (Cu, Ni, Zn and Pb) and nutrient (SO42-) factor, while the 2nd component which was most highly correlated with salinity (0.971) had high loadings for ions (conductivity, salinity and TDS) factor. The 3rd component which was most highly correlated with turbidity (0.982) had high loadings for the nutrients (PO42- and NO3-) and turbidity factor (TSS and turbidity), and the 4th component was most highly correlated with the trace element Cd (0.512). The scatterplot matrix (Figure 4) revealed that the extracted factors had fairly normal distributions.

3.4. Influences of the physicochemical parameters on primary productivity

At $P<0.05$, NPP correlated positively with pH (r=0.808). However, at $P<0.01$, GPP & NPP correlated positively with PO42- ions (r=0.976 & 0.981 respectively), NO3- (r=0.955 & 0.980 respectively) and negatively with turbidity (r=-0.946 & -0.976 respectively) (Table 3).

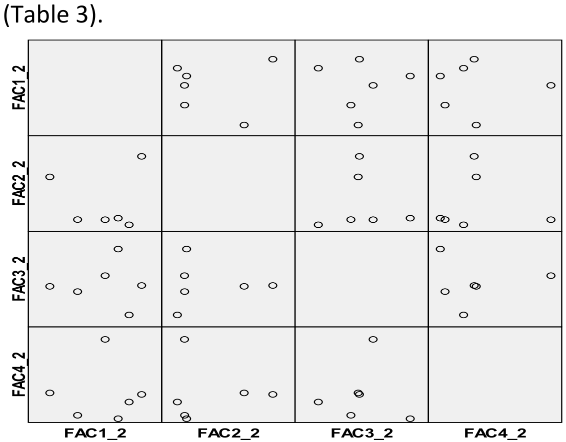

Fig. 4. Scatterplot matrix of component scores of extracted factors

4. Discussion

The mean gross primary productivity recorded in this study was low and comparable to that obtained by Ogbuagu et al. (2011) in the Imo River in Etche, southeastern Nigeria. However, values were lower than those recorded by Ikenweiwe and Otubusin (2005) in Oyan Lake, southwestern Nigeria but higher than that recorded by Adeniji (1990) in Asa Lake, southwestern Nigeria. Elsewhere, values were also higher than those recorded by Simmons et al. (2004) in the US Appalachian coal region. The current work gives a maximum annual productivity of 7.860mgCL-1yr-1 only. This low in situ productivity could be linked to ongoing intense sand mining in the mine ponds bordering the river. Tamuno (2005) and Ogbuagu et al. (2011) had observed that stream sand mining could exert negative influences on the productivity of aquatic ecosystems.

The current work, with higher nutrients and lower turbidity levels contrasts the observations of low nutrients and very high turbidities in Imo River by Ogbuagu et al. (2011). This higher nutrient level may have been introduced from the ongoing perturbations of the benthal regions of the pond during sand mining. It is known that the sediments of aquatic ecosystems is a repository for nutrients and pollutants, as well as home to many biotic components of water bodies (Sikoki and Zabbey, 2006; Bamikole et al., 2009).

The marked spatial variation in productivity reflects varying abiotic influences (especially of nutrients and turbidity) which, as key drivers to primary productivity in aquatic ecosystems, are impacted by sand mining activities in the locations. Productivity varied distinctively between the actively mined and derelict pond locations; with the mined locations recording higher productivity most probably due to the re-suspension and bioavailability of growth nutrients to the autotrophs responsible for photosynthesis in water columns. For example, sampling location 18, with the highest yields in primary productivity also had the highest sulphate and phosphate, as well as high nitrate contents. Nitrate and phosphate ions are key contributors of eutrophication in aquatic ecosystems (Molles, 2002; UNEP GEMS, 2006). Consequently therefore, productivity increased with increasing nutrient levels from the derelict to the actively perturbed locations, to such an extent that it appeared to have deferred increasing turbidities and suspended solids (TSS) which would have otherwise impaired productivity (Ogbuagu et al., 2011).

Similar to the work of Ogbuagu et al. (2011) in Imo River, the current study recorded higher dry than wet season productivities, most probably due to greater contributions of both autochthonous and allocthonous turbidity-causing and productivity-inhibiting suspended solids during the wet season and concentrations of productivity-enhancing nutrients during the dry season.

The very low salinities recorded in the freshwater body indicates possible re-suspension of such salinity constituting cations as Ca2+, Mg2+, Na+ and K+ and anions such as CO32-, HCO2-, SO42- and Cl- from excavations of sediments of the ponds. This is collaborated by increasing values from the actively un-mined to the mined ponds.

The extractions of the principal components analysis clearly reveal two major groups of variables which are key drivers in ecosystems productivity. These are the micro- (Cu, Ni, Zn, Pb, Cd) and inorganic nutrients/ions (SO42-, NO3-, PO42-, conductivity, salinity, TDS), and turbidity factors (TSS and turbidity). The enhancement of productivity by these nutrients, as well as inhibition by turbidity factors have severally been observed and cited in this work. The positive correlations between productivity and NO3- and PO42-, as well as the negative correlations between productivity and turbidity collaborates these observations. The high cumulative percentage variability contributed by these factors (95.05%) further buttress their driver roles in the aquatic system.

The significant correlation between pH and net primary productivity confirms the importance of pH in aquatic productivity and general ecosystems processes. The pH of aquatic ecosystem is closely related to biological productivity, though the tolerance of individual species varies (UNEP GEMS, 2006). Studies have revealed that some pollutants such as the heavy metals are more bioavailable and so have greater toxicities towards aquatic lives, including autotrophic algae, at acidic pH (UNEP GEMS, 2006). The higher productivities recorded in the actively mined locations could thus, also be associated with the observed slightly higher more acidity recorded in the non-mined locations.

5. Conclusion

The primary productivity regime of the sand mined ponds of the Otamiri River was low, with significant spatial variations between the actively mined and derelict pond locations. Productivity was higher in the actively mined than non-mined locations due to higher essential nutrients availability which appeared to undermine a slightly increasing turbidity. Higher productivities were recorded in the dry than wet seasons of the study period. Four factors which formed the PCA extraction solution showed very high loadings for the nutrients and turbidity factors. Observed direct correlations between productivity and the nutrients, and inverse correlations between productivity and turbidity indicate their enhancement and inhibitory roles, respectively in productivity of the aquatic ecosystems. Very low salinities, most probably contributed by re-suspensions of constituent cations and anions from benthal excavations were detected. The all important role of pH in ecosystems productivity was also indicated. Active sand mining appeared to encourage primary productivity in the mine pond of Otamiri River, with the inorganic nutrients and turbidity as key driver impact factors of the process.

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