Investigating Temperature and Nutrients as Drivers of Primary Productivity in Aquatic Environment

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Abstract

An investigation into the relationship between temperature and the nutrients (NO_3^-, PO_4^{3-}, SO_4^{2-}) in pelagial primary productivity of the middle reaches of Otamiri River in Owerri, Southeastern Nigeria was carried out between October and November, 2018 at ten sampling points (OTP 1-OTP 10). The estimation of productivity was made with the light and dark bottle technique. Maximum yields in Gross Primary Productivity (GPP) (0.8738 $mgCL^{-1}d^{-1}$), Net Primary Productivity (NPP) (0.8513 $mgCL^{-1}d^{-1}$), as well as Community Respiration (CR) (0.1613 $mgCL^{-1}d^{-1}$) were recorded at OTP 3, OTP 3 and OTP 8 respectively that had more vegetation covers than in segments without cover. GPP is correlated with PO_4^{3-} ions (r = 0.400), SO_4^{2-} ions (r = 0.418), and water temperature (r = 0.379) ($p < 0.05$), while CR is correlated with SO_4^{2-} ions (r = 0.500) ($p < 0.01$). The variability of GPP increased mildly with increasing temperature and the nutrients; with predicted regression model productivities of 0.1388, 0.5621, and 0.6066 $mgCL^{-1}d^{-1}$, corresponding with mean values of 28.41°C, 0.33 mg/L, 1.04 mg/L and 10.25 mg/L recorded for temperature, NO_3^-, PO_4^{3-}, and SO_4^{2-} ions concentrations. Mean GPP was estimated to result in a comparatively low annual productivity of 188.75 $mgCL^{-1}yr^{-1}$. Conservation and restoration of riparian vegetation covers in watershed corridors of the river for optimal driver roles were recommended.

Keywords

Primary Productivity, Otamiri River, Nutrients, Eutrophication, Riparian Vegetation

1. Introduction

It is known that water quality is affected by a range of chemical, physical, biological, and biochemical attributes; some of which could provide a general indication of water pollution while others enable the direct tracking of pollution sources. According to Ogbuagu (2014), a biochemical technique that has been used to obtain indirect information about the productivity of an aquatic system is primary productivity; the production of organic compounds from aquatic CO_2, mainly through photosynthesis, with chemosynthesis being much less important (Global Change, 2008).

Brandt in 1899 and 1902 first proposed that primary productivity is dependent upon the supplies of nitrate and phosphate to natural waters (Ketchum et al., 1958), even though nutrients enrichment in excess could lead to eutrophication. Our knowledge and ability to manage aquatic eutrophication has expanded greatly during the intervening three decades, as summarized in several synthetic reviews by Smith et al. (1999) and Smith (2003, 2006). It can now be argued that, in general, the results of nutrient over-enrichment tend to be negative, with beneficial effects being rare or accidental. In particular, eutrophication often has a strongly negative economic dimension (Segerson & Walker, 2002). In England and Wales for example, the damage costs of freshwater eutrophication alone have been estimated at £75 - 114 million per year (Pretty et al., 2003). Similarly, the economic consequences of estuarine and coastal marine eutrophication can be very substantial, and are expected to increase over time worldwide as human populations grow and move into coastal communities.

In recent times, the demands of increasing population and associated urbanization (such as sand, mostly used for buildings and other infrastructural constructions) have placed serious pressure on the resources of the Otamiri River; one of the major rivers in southeastern Nigeria. Other ongoing anthropogenic activities include devegetation of the river corridors as reported by Ogbuagu and Okoli (2013). Elsewhere, several reports exist on the impact of anthropogenic activities on the primary productivity of aquatic ecosystems, especially those impacts on the autotrophic biota responsible for primary production in the ecosystem. For example, removal of riparian vegetation could cause direct solar irradiations to impact the temperature regime of the river and so, alter, not only the basic physical and chemical processes necessary for the survival of aquatic biota (Adams, 2010; Ogbuagu et al., 2011), but also several other physicochemical attributes of a river (Don-Pedro, 2009). Other than nutrients (Simmons et al., 2004), solar irradiation and temperature variations are reported as major limiting factors to primary productivity by phytoplankton (Vaillancourt et al., 2003). Consequently therefore, changes in primary productivity have been causally linked to temperature and the nutrient status of aquatic ecosystems for over a century. The aim of the study was to investigate the possible relationship between water temperature, nutrients availability and primary productivity regime of the Otamiri River in Owerri, Nigeria.

2. Materials and Methods

2.1. The Study Area

The Otamiri River in Owerri serves for domestic, fisheries and artisanal sand mining uses as it courses through the Federal University of Technology, Owerri (FUTO) campus, onto the suburbs, and then to the neighbouring Rivers State, where it first confluences with the Oge-Ochie, and then Imo Rivers. The FUTO is sited in Owerri, a metropolitan city located between latitudes 05˚29'06 s and longitude 07˚02'06 s (Figure 1) in the southeastern part of Nigeria. The area is characterized by two major seasons; a wet season (which last from April to November) and a dry season (which last the rest of the year). Annual rainfall varies between 1500 and 2200 mm, with mean daily minimum and maximum temperature ranges of between 19 - 24 and 28˚C - 35˚C respectively. Average humidity is about 80%, and the vegetation of the area is semi-deciduous forest whose density has been altered by farming and deforestation.

2.2. Sampling Locations

Ten sampling locations were established about 50 metres apart along the course of the river within the FUTO. During sampling, in-stream sand mining activities were ongoing at several locations on the river.

2.3. Light and Dark Bottle Experiment

The Light and Dark Bottle technique of Gaarder and Gran (1927), as applied by Ogbuagu and Ayoade (2011) for the estimation of primary productivity was
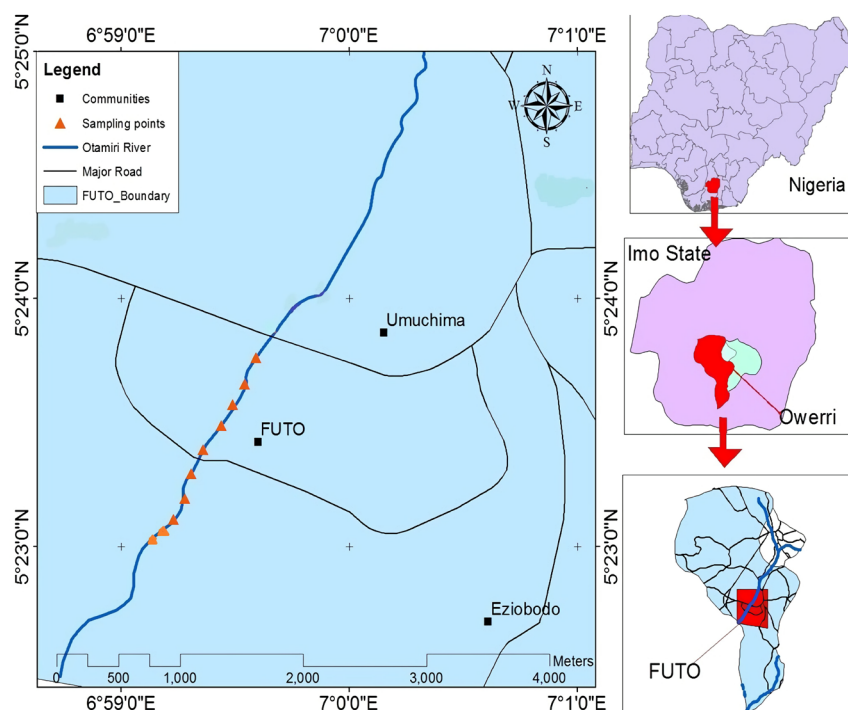

Figure 1. Map of the Otamiri River in FUTO showing the sampling points.

used. Three identical transparent 1-litre bottles; one covered with black polythene (Dark bottle) and the others not (Light bottles) were filled with the river water and stoppered while still submerged. The dissolved oxygen content of the first light bottle (DO_1) was determined immediately with an HANNA HI 9828 pH/ORP/EC/DO meter, while the other two bottles were suspended in the pelagial zone where the water had been taken with the aid of an inextensible rope for about 4 hours incubation period in a sunny afternoon (Ikenweiwe & Otubusin, 2005). The remaining two bottles were harvested immediately after the incubation period and their dissolved O_2 contents (DO_L & DO_D) determined. The experimental setup was done in replicates. Primary productivity was calculated in mg of O_2 produced per litre of water per day according to the formula:

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

where GPP = Gross Primary Productivity, NPP = Net Primary Productivity, and CR = Community Respiration.

The productivity results were however converted to their carbon equivalents by multiplying the O_2 values by the factor 0.375 (Global Change, 2008).

2.4. *In Situ* Physicochemical Measurements and Water Sample Collection

Temperature of pelagial water was determined electrometrically *in situ* with the mercury-in-glass thermometer. Water samples were collected in 2 litres plastic bottles that had been severally rinsed with the river water. Samples were then transported to the laboratory in iced coolers to maintain their integrity.

2.5. Laboratory Analysis

Standard methods of APHA (1998) were adopted in the analysis of the nutrient ions. The cadmium reduction method was employed in the determination of NO_3^- ions; whereby a cadmium-based reagent pillow was added into 25 mL of the water sample in a cuvette, shaken for 1 minute, and allowed to stand for another 5 minutes for complete reaction to occur. The absorbance and concentration in mg/L was read at 500 nm wavelength using HACH DR 2010 UV-visible spectrophotometer.

The barium chloride (Turbidometric) method was adopted in the determination of SO_4^{2-} ions. The barium chloride-based powdered reagent pillow was added into 25 mL of water sample. The mixture was properly mixed and allowed to stand for 5 minutes for reaction to occur. The absorbance and concentration in mg/L was read at 450 nm wavelength using HACH DR 2010 UV-visible spectrophotometer.

For the determination of PO_4^{3-} ions, the ascorbic acid method was adopted. Ascorbic acid based reagent powdered pillow was added into 25 mL of the water sample in a cuvette. The sample was allowed to stand for 2 minutes for reaction to occur. The absorbance and concentration in mg/L was read at 890 nm wavelength using HACH DR 2010 UV-visible spectrophotometer.

2.6. Statistical Analysis

Descriptive statistics were used to represent primary productivity variables. The Pearson correlation coefficient, was used to determine possible relationships between productivity variables and the predictors—temperature, NO_3^-, SO_4^{2-}, and PO_4^{3-} ions. The linear regression was used to model the values of gross primary productivity based on its linear relationship to the assumed predictors. The regression model assumes that there is a linear relationship between the dependent variable and each predictor. The relationship is described in the following formula:

$$y_j = b_0 + b_1 x_{il} + \cdots + b_p x_{ip} + e_i \tag{2}$$

where y_i is the value of the ith case of the dependent scale variable,

p is the number of predictors,

b_j is the value of the jth coefficient, $j = 0, ..., p$,

x_{ij} is the value of the ith case of the jth predictor,

e_i is the error in the observed value for the ith case.

The one-way ANOVA was used to determine spatial homogeneity in mean variance of the productivity and predictor variables at $p < 0.05$. Mean separation was achieved with the post-hoc Duncan Multiple Range test at the 95% confidence interval.

3. Results

3.1. Descriptive and Spatial Variations in Primary Productivity and Predictor Parameters

GPP, NPP and CR varied from 0.91 - 2.33 (1.38 ± 0.07), 0.19 - 2.27 (1.13 ± 0.08) and 0.04 - 0.44 (0.21 ± 0.03) mgCL^{-1}d^{-1} respectively. However, water temperature, NO_3^-, PO_4^{3-} and SO_4^{2-} ion concentrations varied as follows: 28.07 - 28.71 (28.41 ± 0.02)°C, 0.16 - 1.29 (0.33 ± 0.04) mg/L, 0.70 - 1.30 (1.04 ± 0.03) mg/L and 8.00 - 11.40 (10.25 ± 0.19) mg/L respectively.

Highest GPP estimate of 2.33 mgO$_2$L^{-1}d^{-1} (0.8738 mgCL^{-1}d^{-1}), NPP estimate of 2.27 mgO$_2$L^{-1}d^{-1} (0.8513 mgCL^{-1}d^{-1}) and CR estimate of 0.43 mgO$_2$L^{-1}d^{-1} (0.1613 mgCL^{-1}d^{-1}) were recorded at OTP 3, OTP 3 and OTP 8 respectively (Figure 2). However, least GPP (0.95 mgO$_2$L^{-1}d^{-1} = 0.3563 mgCL^{-1}d^{-1}), NPP (0.84 mgO$_2$L^{-1}d^{-1} = 0.3150 mgCL^{-1}d^{-1}) and CR estimates (0.06 mgO$_2$L^{-1}d^{-1} = 0.0225 mgCL^{-1}d^{-1}) were recorded at OTP 6, OTP 6 and OTP 3 respectively (Figure 2).

The one-way ANOVA revealed that except in NO_3^- ion concentrations (Sig. F value = 0.315), all other predictor and primary productivity variables differed significantly across the sampling locations at $p < 0.05$. The post-hoc Duncan Multiple Range test further revealed that in GPP, the spatial differences were between sampling locations other than SL 4 & SL 5, SL 4 & SL 7, SL 7 & SL 9, SL 8 & SL 10, SL 9 & SL 10, SL 2 & SL 9, SL 2 & SL 10, SL 4 & SL 9, and SL 2 & SL 7 (Table 1). In NPP, the differences were between locations other than SL 2 & SL 4
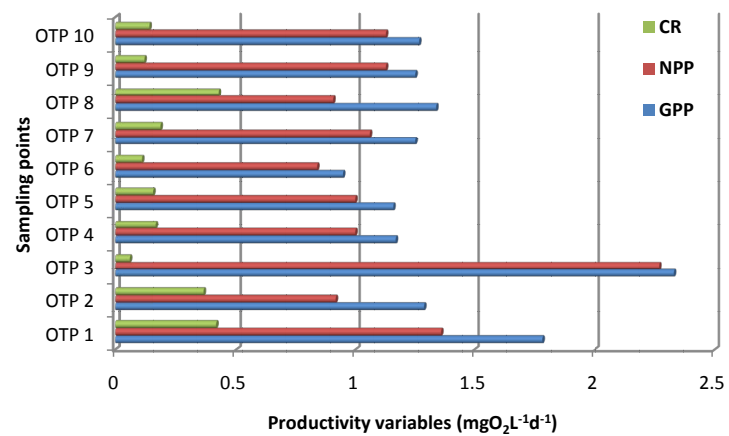
Figure 2. Spatial variations in Gross and Net Primary Productivity (GPP & NPP) and Community Respiration (CR) of the Otamiri River in Owerri, Nigeria.
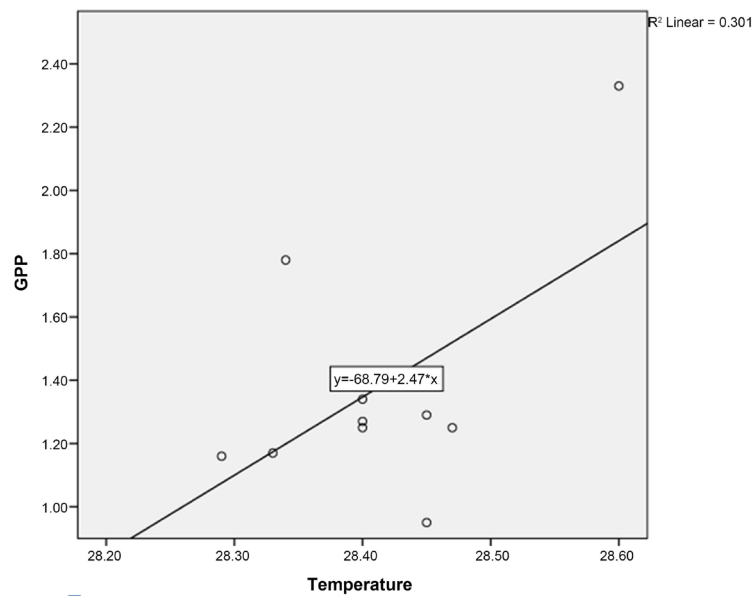

Figure 3. Linear regression scatterplot of GPP by temperature regime of the Otamiri River in Owerri.

Table 1. Mean separation in primary productivity and predictor parameters of the Otamiri River in Owerri, Nigeria.

Variables	Sampling Locations (OTP)									
	1	2	3	4	5	6	7	8	9	10
GPP	1.7767^f	1.2900^d	2.2867^g	1.1833^{bc}	1.1600^b	0.9500^a	1.2500^{cd}	1.3400^e	1.2500^{cd}	1.2700^{de}
NPP	1.3633^c	0.9200^{ab}	2.2167^d	0.9867^{ab}	1.0000^{ab}	0.8400^{ab}	0.7600^a	0.9100^{ab}	1.1300^{bc}	1.1300^{bc}
CR	0.4200^c	0.3700^c	0.0700^a	0.1333^a	0.1600^{ab}	0.1100^{ab}	0.1900^b	0.4300^c	0.1200^{ab}	0.1400^{ab}
Temperature	28.3400^a	28.4500^{ab}	28.6033^b	28.3300^a	28.2900^a	28.4533^{ab}	28.400^a	28.4000^a	28.4700^{ab}	28.400^a
NO_3^-	0.6233^b	0.3000^{ab}	0.4000^{ab}	0.2000^a	0.2000^a	0.3500^{ab}	0.300^{ab}	0.2800^{ab}	0.2800^{ab}	0.3300^{ab}
PO_4^{3-}	1.1000^{bc}	1.000^{abc}	1.2000^c	1.2000^c	0.8000^a	0.900^{ab}	1.100^{bc}	1.2000^c	1.000^{abc}	0.9000^{ab}
SO_4^{2-}	11.000^{de}	11.2000^e	10.8000^{de}	11.000^{de}	8.5000^a	9.000^{ab}	10.5000^{de}	11.000^{de}	9.5000^{bc}	10.000^{cd}

Values with same superscripts along same rows are not significantly difference at $p < 0.05$; GPP = Gross Primary Productivity, NPP = Net Primary Productivity, CR = Community Respiration.

& SL 5 & SL 6 & SL 8, SL 2 & SL 7, SL 1 & SL 9 & SL 10, and in CR, it was between locations other than SL 1 & SL 2 & SL 8, SL 3 & SL 4, and SL 5 & SL 6 & SL 9 & SL 10. Significant spatial differences were also observed in PO_4^{3-} ion concentrations between locations other than SL 5 and SL 1 and SL 3 and SL 4 and SL 7 and SL 8, and in SO_4^{2-} ion concentrations, it was between locations other than SL 5 and SL 1-SL 4 and SL 7-SL 10 (Table 1).

3.2. Relationships between Primary Productivity and Predictor Variables

There were significant Pearson's correlationships (r) existing between the primary productivity parameters and predictor variables (Table 2). At $p < 0.05$, GPP correlated positively with PO_4^{3-} (r = 0.400), SO_4^{2-} (r = 0.418) and water temperature (r = 0.379), and NPP correlated with temperature (r = 0.375). However, at $p < 0.01$, CR correlated with SO_4^{2-} ions (r = 0.500). The linear regression scatterplot of GPP by temperature shows that variability of GPP increased with increasing temperature (Figure 3). However, the significant value of the F-statistics (0.101) indicates that the variation explained by the model could be due to chance at $p < 0.05$. The Regression Sum of Square (0.420) and Residual Sum of Square (0.976), which are unequal, as well as the coefficient of determination (R^2 = 0.301) all indicate that less than half the variation in GPP could be explained by the model. The multiple correlation coefficient, R, is average (R = 0.548), indicating an average relationship.

The model further shows that:

$$y = -68.79 + (2.47)x \tag{3}$$

i.e. the expected yield in GPP = −68.79 + 2.47 × temperature (4)

The residual, which is the difference between the observed and model-predicted values of the dependent variable (GPP) (Figure 4) shows the shape of the histogram approximately following the shape of the normal curve. The P-P plotted residuals (Figure 5) followed the prescribed 45° line; indicating that neither the histogram nor the P-P plot violated the normality assumption. The plot of residuals

Table 2. Correlation coefficient (r) matrix between Primary Productivity and Predictor variables in the Otamiri River, Owerri, Nigeria.

	GPP	NPP	CR	NO_3^-	PO_4^{3-}
NPP	0.883**				
CR	0.057	−0.214			
NO_3^-	0.349	0.250	0.226		
PO_4^{3-}	0.400*	0.216	0.084	0.111	
SO_4^{2-}	0.418*	0.189	0.500**	0.212	0.526**
Temp	0.379*	0.375*	-0.129	0.100	0.144

* = significant at $p < 0.05$, ** = significant at 0.01, GPP = Gross Primary Productivity, NPP = Net Primary Productivity, CR = Community Respiration, Temp = Water temperature.
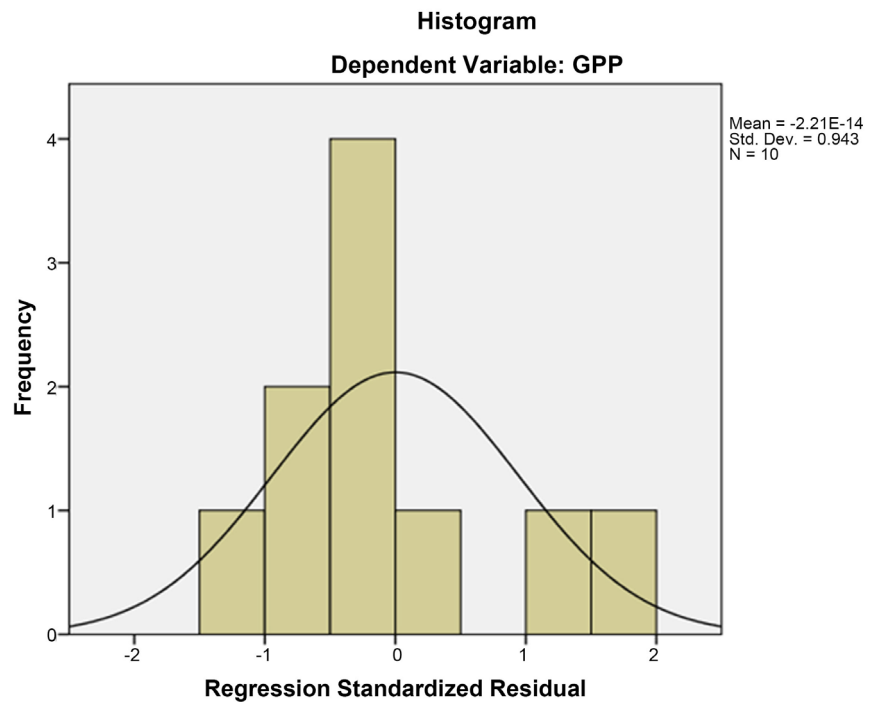
Histogram

Dependent Variable: GPP

Figure 4. Regression Standardized Residual plot of Normality of Error Term in GPP by temperature regime of Otamiri River in Owerri.

Normal P-P Plot of Regression Standardized Residual
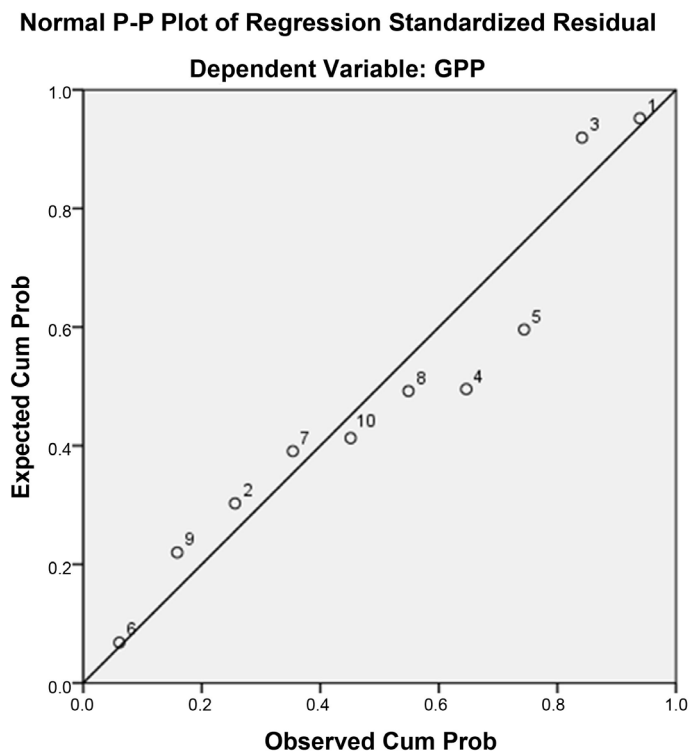
Dependent Variable: GPP

Figure 5. P-P plot of Normality of Error Term in GPP of the Otamiri River in Owerri.

by the predicted values reveals that the variance of the errors increased with increasing predicted GPP.

Figure 6 shows the linear regression scatterplot of GPP by NO_3^-, and reveals that the variability of GPP increased with increasing nitrate ion concentrations. However, the sig. value of the F-statistics (0.125) indicates that the variation explained by the model could be merely due to chance at $p < 0.05$. The multiple correlation coefficient, R, is average (R = 0.518), indicating an average relationship; even though the coefficient of determination (R^2 = 0.268), and the Regression Sum of Squares (0.375) and Residual Sum of Squares (1.021), which are unequal all indicate that less than 1/1 of the variation in GPP could be explained by the model.

The model shows that:

$$y = 0.4 + (3.33)x \tag{5}$$

i.e. the expected yield in GPP = 0.4 + 3.33 × Nitrate ions   (6)

The residual (Figure 7) shows a histogram approximately similar to the shape of the normal curve.

The outcome linear regression scatterplot of GPP by PO_4^{3-} ion concentrations reveals that the variability of GPP increased with increasing phosphate ions (Figure 8). The sig. value of the F-statistics (0.120) indicates that the variation explained by the model could, again be due to chance at the 95% confidence limit. The multiple correlation coefficient, which is average (R = 0.524), indicates a strong relationship, even though the coefficient of determination (R^2 = 0.274), as well as the Regression (0.383) and Residual Sums of Squares (1.013) which are unequal, all indicate that much less than 1/2 of the variation in GPP could be explained by the regression model.
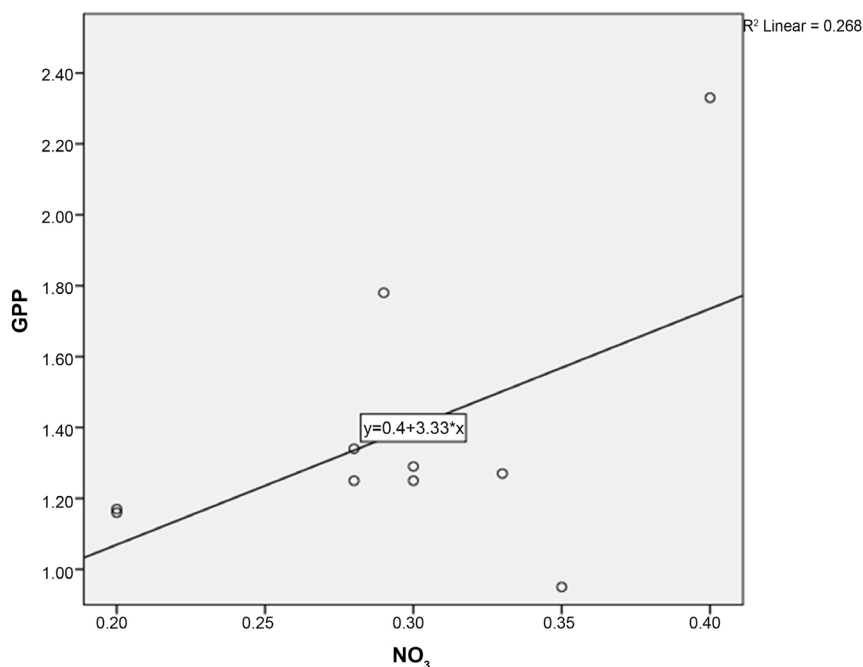

Figure 6. Linear regression scatterplot of GPP by NO_3^- ion concentrations of the Otamiri River in Owerri.

Histogram

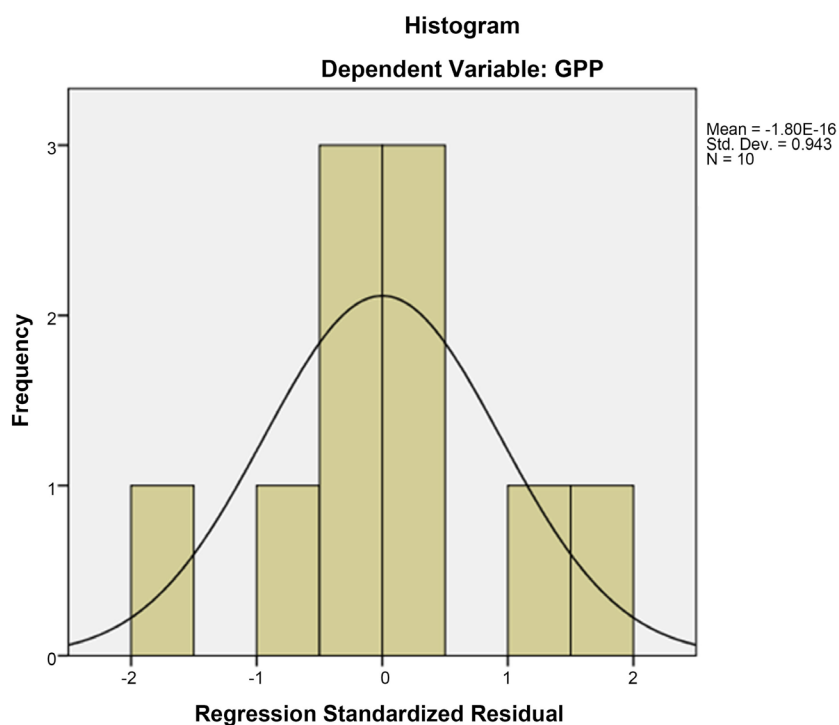**Dependent Variable: GPP**

Figure 7. Regression Standardized Residual plot of Normality of Error Term in GPP by NO_3^- ion concentrations of Otamiri River in Owerri.
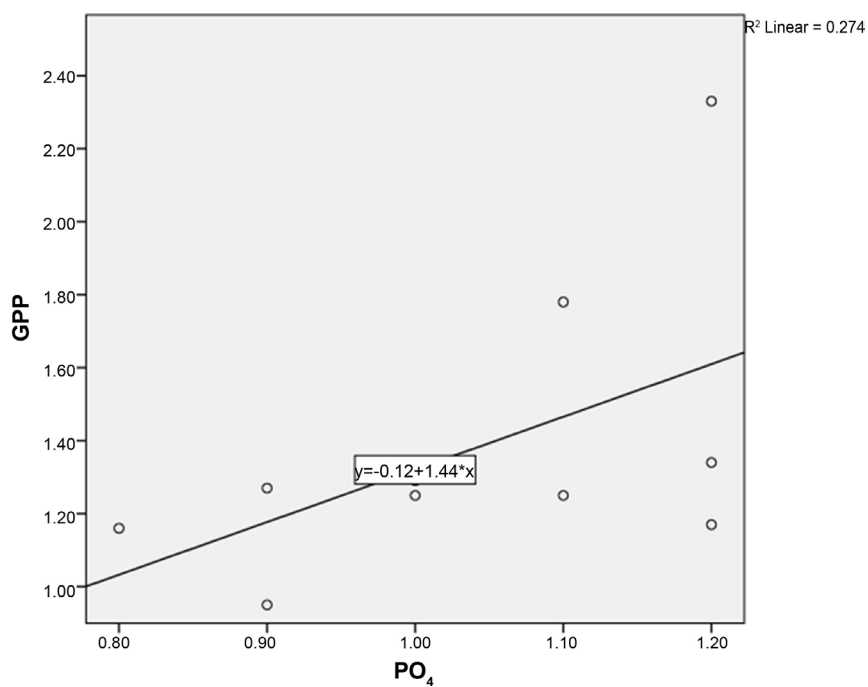

Figure 8. Linear regression scatterplot of GPP by PO_4^{3-} ion concentrations of the Otamiri River in Owerri.

The model further shows that:

$$y = 0.12 + (1.44)x \tag{7}$$

i.e. the expected yield in GPP = 0.12 + 1.44 × phosphate ions　　(8)

Again, the difference between the observed and model-predicted values of the dependent variable (GPP) (residual) (**Figure 9**) reveals the shape of the histogram approximately following the shape of the normal curve.

For SO_4^{2-}, the linear regression scatterplot shows that the variability of GPP increased with increasing sulphate ion concentrations (**Figure 10**). Again, the significant value of the F-statistics (0.178) indicates that the variation explained by the model could be due to chance at $p < 0.05$. The multiple correlation coefficient, R is less than average (R = 0.462), indicating a weak relationship, even as the coefficient of determination ($R^2 = 0.214$) and Regression (0.298) and Residual sums of squares (1.097) which are unequal indicate that less than 1/2 of the variation in GPP could be explained by the model.

The model further shows that:

$$y = 0.58 + (0.19)x$$　　(9)

i.e. the expected yield in GPP = 0.58 + 0.19 × sulphate ions　　(10)

The residual shows the shape of the histogram not following the shape of the normal curve (**Figure 11**). This histogram is therefore not acceptably close to the normal curve, and therefore indicates skewness.

4. Discussion

The current study revealed that primary productivity varied slightly across the
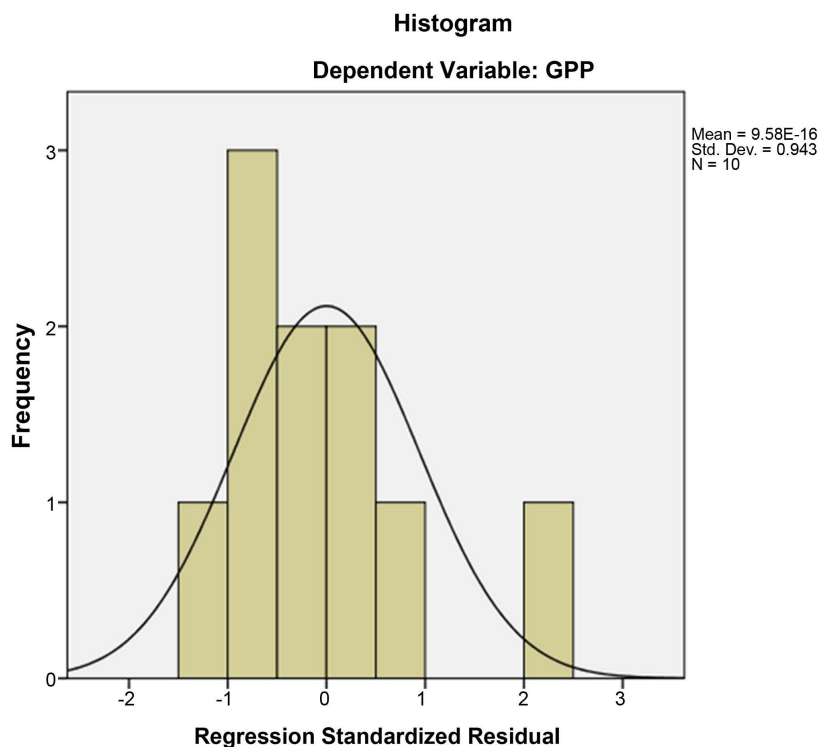

Figure 9. Regression Standardized Residual plot of Normality of Error Term in GPP by PO_4^{3-} ion concentrations of Otamiri River in Owerri.
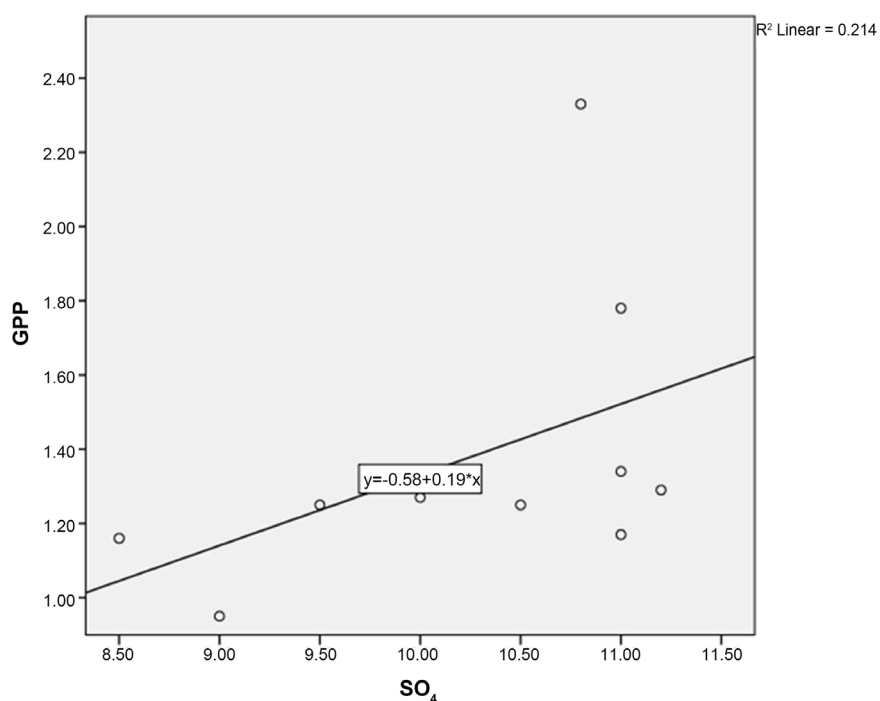
Figure 10. Linear regression scatterplot of GPP by SO_4^{2-} ion concentrations of the Otamiri River in Owerri.
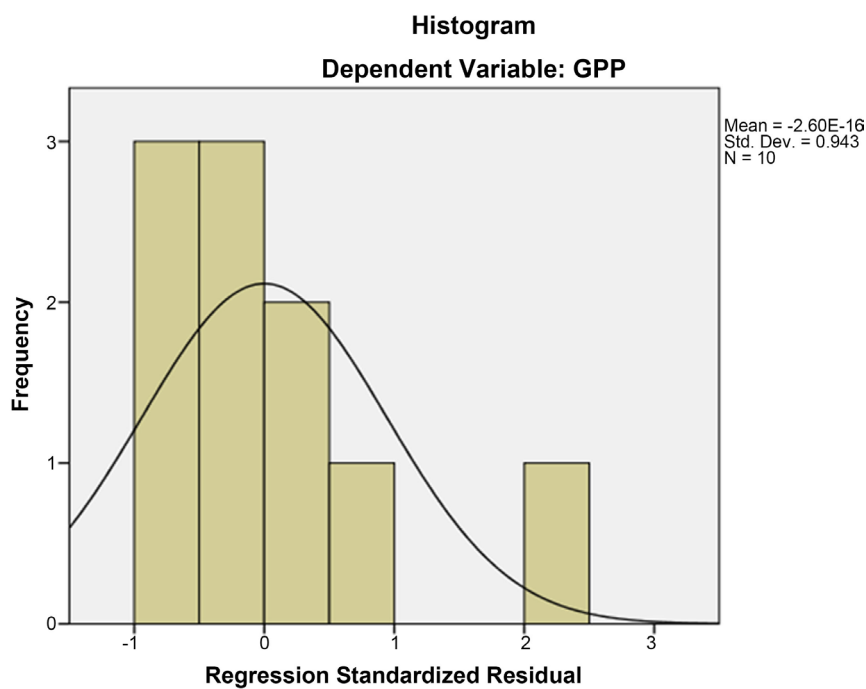

Figure 11. Regression Standardized Residual plot of Normality of Error Term in GPP by SO_4^{2-} ion concentrations of Otamiri River in Owerri.

sampling points. For example, point OTP 3 recorded the highest productivity and OTP 8, the highest community respiration estimates; indicating that the respective points were most productive and inhabited by the most active aerobic

autotrophic microorganisms. Net primary productivity followed the same spatial trend as gross primary productivity. OTP 6 that recorded the least productivity had fewer riparian vegetation cover than the rest sampling points during this period. A negative impact of removal of riparian vegetation on primary productivity of a freshwater aquatic ecosystem had been explored by Ogbuagu and Okoli (2013); wherein they established that the removal of riparian covers exposed some segments of the Otamiri River to direct solar irradiation and consequent excessive and unfavourable temperature elevations. The current study contradicts that of Ogbuagu and Okoli (2013) in its revelation that that productivity increased with increasing temperature regime of the river. However, this current observation is in concordance with the work of Truitt (2006) in four ponds, wherein he observed that as the temperature of the ponds rose, there was more dissolved oxygen (leading to higher productivity), thus allowing the oxygen to be saturated even more. A fact that is underscored here is that there exist is temperature threshold for the enhancement of this biochemical process, above which the productivity process will be hampered. Accordingly, the UNEP GEMS (2006) states that temperature affects the speed of chemical reactions, the rate of photosynthesis (primary productivity) by algae and aquatic plants, the rate of metabolism in organisms, as well as the interactions of pollutants, parasites and other pathogens with aquatic residents. It also influences the solubility of dissolved oxygen (which was used to estimate productivity in the current study) and other materials (e.g. CO_2) required for photosynthesis in water column.

Though higher temperature regimes in water column would reduce the availability of the all-important dissolved CO_2 necessary for primary production, the linear regression model output in the current study indicates that an increase by the recorded mean temperature value would result in about 0.1388 $mgCL^{-1}d^{-1}$ increases in productivity of the segment of the river.

The mean Gross Primary Productivity (GPP) recorded in the present study (0.1379 ± 0.02 $mgO_2L^{-1}d^{-1}$) is low, especially when compared with the works of Samaan (1971) in Nasser Lake (4.405 $gO_2m^{-2}d^{-1}$), Mbagwu and Adeniji (1994) in Mariut Lake (4.481 $gO_2m^{-2}d^{-1}$) and Ikenweiwe and Otubusin (2005) in Oyan Lake, all in Nigeria (3.9 $gO_2m^{-2}d^{-1}$). However, it was higher than the mean value of 0.00125 $gO_2m^{-2}d^{-1}$ recorded by Adeniji (1980) in Bakolori Lake, Sokoto State and 0.041 $gO_2m^{-2}d^{-1}$ recorded by Adeniji (1990) in Asa Lake in Ilorin, all in Nigeria. This low productivity would correspond with low phytoplankton abundance in the study, which may have in turn been created by intense ongoing in-stream sand mining activities. Ogbuagu and Samuel (2014) had observed that in-stream sand mining activity could exert significant negative impacts on the ecodynamics of the river. The current study therefore would result in a low annual productivity estimate of about 503.335 $mgO_2L^{-1}yr^{-1}$ (=188.751 $mgCL^{-1}d^{-1}$). However, this productivity was unequal spatially, with sampling location 3 recording highest GPP due to its relatively pristine disposition.

The low nutrient levels recorded in this study, especially of nitrate and phosphate ions, as also observed by Guildford and Hecky (2000) elsewhere, acted as

productivity-limiting factors that exerted influences on photosynthesis by the autotrophs. Direct enhancing influences of the nutrients on primary productivity have been noted by Ogbuagu et al. (2011) in Imo River in Etche, Nigeria and Simmons et al. (2004) in an acid mine drainage treatment pond in the United States. Accordingly, Net Primary Productivity (NPP) and Community Respiration (CR) values closely followed the trend of GPP. This indicates a stable community composition of autotrophs utilizing part of the gross production.

Both nitrate, phosphate and sulphate ions exerted positive influences on primary productivity in this work. Given the mean values of NO_3^-, PO_4^{3-}, and SO_4^{2-} ion concentrations, the regression models in the current work would result in gross productivity estimates of about 0.5621, 0.6066, and 0.9478 mgCL^{-1}d^{-1} respectively. Several other studies, including that of Guildford and Hecky (2000) have observed that phosphorus (as in phosphates) and nitrogen (as in nitrates) loadings specifically are primary causes of nutrient enrichment (eutrophication) of inland waters, which could lead to increased primary production. Conversely, Truitt (2006) had also observed that as the variables contributing to primary productivity (DO, nitrogen, and phosphorus) increased, the gross and net primary productivity decreased uniformly.

5. Summary/Conclusion

Yields in primary productivity were generally low, and segments of the river with vegetation covers had higher yields than segments without cover. Productivity was mildly limited by temperature and nutrients availability.

6. Recommendations

The following recommendations are made:
- Conservation and restoration of riparian covers as watershed management approaches should be embarked upon on river system;
- Monitoring of anthropogenic activities, such as in-stream sand mining and discharge of untreated domestic wastes should be carried out so as to create reduction in aquatic pollution;
- Possible improvement of productivity of the river through iron fertilization trials should be explored.

Acknowledgements

We acknowledge the assistance of Transcontinental Petrotech (Nigeria) Limited in supply of the *in situ* analytical equipment used in this study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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