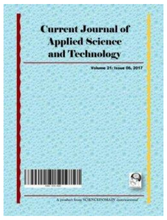

Current Journal of Applied Science and Technology

28(1): 1-9, 2018; Article no.CJAST.39762
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Development of Multiple Regression Model in Predicting the Dissolved Oxygen Deficit of Ntawaogba River

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Authors' contributions

This research was carried out between both authors. Author NUJ managed the general theoretical frame work/ literature review, design analysis and ensured that the results met objectives of the study while author CAD performed the field sampling, data analysis and raised the initial draft. Both authors met severally, agreed and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2018/39762
Editor(s):
(1) Dr. Sylwia Myszograj, Professor, Department of Water Technology, Sewage and Wastes, University of Zielona Gora, Poland.
(2) Dr. Rares Halbac-Cotoara-Zamfir, Professor, Department of Hydrotechnical Engineering, "Politehnica" University of Timisoara, Romania.
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Reviewers:
(1) Basak Taseli, Giresun University, Turkey.
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(3) Ahmed Karmaoui, Morocco.
Complete Peer review History: http://www.sciencedomain.org/review-history/25194

Original Research Article

Received 29th January 2018
Accepted 1st May 2018
Published 20th June 2018

ABSTRACT

This study developed a multiple regression model for predicting the dissolved oxygen deficit for Ntawaogba River in Port Harcourt, Rivers State Nigeria. The instrument used for field sampling includes 1L sample container, Garmin GPS, EXTEC water equipment/Horiba, BOD bottle, Floaters, Measuring Tape, Stop watch, Ice chest and sample log book. Ten samples were collected along the river stretch at distance of 100 m apart. Water quality analysis on the samples showed that ammonia and total coli form counts were higher than Federal Ministry of Environment recommended limits and the dissolved oxygen value ranges from 3.65-5.6mg/l. The computed deoxygenating rate constant was 0.38 and reaeration rate constant was 0.99. The Fair ratio, "f" for the river was 2.55; the dissolved oxygen (DO) deficit at initial time was 3.85mg/l and at critical time ($1.72d^{-1)}$ the critical deficit was 2.48 mg/l respectively. Multiple regression model was developed for dissolved oxygen

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deficit of the study river using appropriate excel software; considering BOD, temperature and river flow with constant $b_0 b_1 b_2 b_3$ to be 2.690293, 0.899899, -0.16754, and 0.042823 for respective sample points down the river at any point. These results indicated that the river is polluted and the fluctuation in DO values was attributed to constant waste discharges into the river from various sources and the hydraulic condition of the river.The study recommended that waste discharge into the river should be discouraged and monitored to mitigate further degradation.

Keywords: Regression model; deoxygenating rate; excel software; reaeration rate; hydraulic condition.

1. INTRODUCTION

Naturally, rivers have abilities for self-purification upon introduction of contaminants. This self-purification capacity (otherwise called assimilative capacity) however, is limited by many factors such as waste loading, inherent river conditions, climatic factors and physical conditions, just to mention a few [1,2]. Thus, continuous discharge of untreated waste into a river may overstress it beyond its tolerance limits with deleterious effects on such river.

It therefore means that the assimilative capacity of the river should be closely monitored to ensure it does not exceed its ability to safely receive wastes that are being disposed in it and these can be fully studied by checking the dissolved oxygen content in the water body.

Many rivers and water bodies in developing cities suffer greatly from poor waste management practices in the area [3]. Waste from various sources including but not limited to domestic, commercial and industrial origins are being discharged into canals, drainage systems and rivers serving as ultimate waste receptacles [4]. This practice has led to continual degradation of surface water qualities and underground water contamination in many cases [5]. In surface water quality monitoring, there are some key parameters which included the water pH, temperature, chloride, nitrate and ammonia, sulphate and phosphate, dissolved oxygen, and biochemical oxygen demand which can provide vital information on the overall health of the water body. Dissolved oxygen which refers to the amount of gaseous oxygen dissolved in water and oxygen is a basic requirement for life, both in terrestrial and aquatic environments [6]. It is an important parameter used to check the health of water bodies, such that the level of dissolved oxygen in water can be used to decide whether or not the water is polluted.

Typically, the concentration of oxygen present in water will depend largely on the water temperature, organic load, water velocity for flowing water, wind speed, mixing in the water, among others [7]. For a water body to sufficiently support life, a minimum of 4.0 mg/l dissolved oxygen is required. A very healthy aquatic environment will have oxygen between 5.0 mg/l and about 14.0 mg/l at saturation. The discharge of wastes into water bodies will cause a drop in the concentration of dissolved oxygen [8]. It then means that continuous discharge of such wastes will further degrade the water quality by diminishing its oxygen content and making the water unfit for its purpose. In water bodies (streams, lakes, rivers), there is a minimum concentration of oxygen required to support living organisms.

The equation derived by Streeter and Phelps (1925) provides a useful tool for modelling the oxygen content of a water receiving wastes, such that reliable information about the health and assimilative capacity of the water can be ascertained [9]. Though the Streeter and Phelps equation is only applicable to point source pollution and does not account for oxygen demand by sediment and loss of oxygen through other means other than breaking down of organic matter. And the ability for a river to self-purify itself is dependent on waste load, dilution, and temperature.

2. STUDY AREA

Ntawaogba River is located in Port Harcourt, Rivers State of Nigeria. It lies on the South-South geopolitical zone at latitudes $4^0$43’23’’ North and Longitudes $6^0$55’15’’ East on the map of Nigeria [1]. It is one of the water bodies in Port Harcourt and Niger Delta that serve as receptacles for various kinds of wastes generated in the region [10]. The practice of waste disposal arising from lack of proper waste management systems has made many rivers in Port Harcourt metropolis

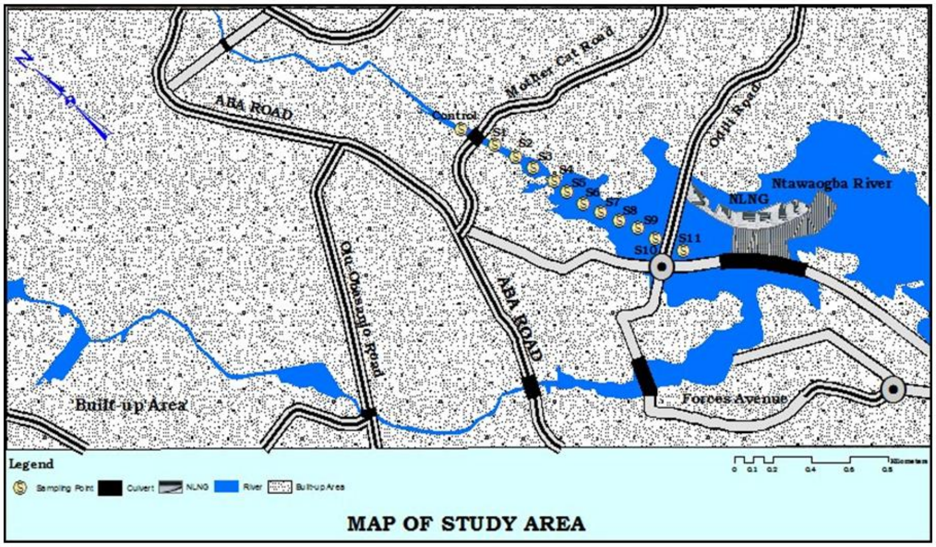

Fig. 1. Map of the study area in Rivers State, Nigeria

in rivers state Nigeria, to be more vulnerable to pollution from municipal wastes, among other waste sources [12].

3. METHODOLOGY

The study of the Ntwaogba River was conducted within a distance of 1 km. and the research scope covers samples collection for 10 points at 100 m interval distance with the first point as control upstream, using scientifically approved methods, American water works association (AWWA, 1997). The distance of sampling was measured using a Global Positioning System (GPS). The study parameters under study include: pH, BOD, COD, DO, electrical conductivity, ammonia and temperature which was compared with Federal Ministry of Environment Standard. The sampling points were labelled on a sample log as PA, PB, PC...PJ to represent Point A, Point B, and Point C...Point J for the ten points, respectively.

The field parameters measured include temperature, pH, turbidity, dissolved oxygen (DO), salinity and electrical conductivity (EC) using EXTEC water meter and Horiba. On completion of the in-situ measurements, samples were collected in appropriate sample containers and preserved at 4ºC in ice chest to maintain the integrity while being transferred to the laboratory. Flow velocity, width and water depth were measured at each point to determine the respective average values with the use of floaters, stopwatch and measuring tape.

De-oxygenation rate constant is the rate at which oxygen is depleted in the water. It is expressed per day as written in Equation one, computed using the Thomas slope graphical method.

$$(t/y)^{1/3} = (K_1 L_o)^{-1/3} + K^{2/3}/6L_O^{1/3,} \quad (1)$$

Where

t = time at sample stations (day)
y = BOD that has been exerted(mg/L)
K = reaeration rate constant to base 10(day^{-1})
Lo= ultimate BOD.(mg/L)

From graph

$$K_1 = 2.61\frac{B}{A} \quad (2)$$

Where

B= slope of the best fit line
A= intercept of the best fit line on the ordinate axis.

$$L_o = \frac{1}{2.3k_1A^3} \quad (3)$$

Correcting deoxygenating rate constant to any other temperature, the equation four is applied

$$K_1 = K_{20}\Theta^{(T-20)} \quad (4)$$

Reaeration rate constant by O' Connor and Dobbins was used to analyses the K_r of the river using the stream conditions.

$$K_r = \frac{3.9V^{1/2}}{H^{3/2}} \quad (5)$$

Where

V=average velocity of the stream
H=average depth

Multiple regression model was developed to estimate the dissolved oxygen deficit at each point downstream. By relating with multiple factors (BOD, DO and Discharge). A method proposed by Churchill and Buckingham (1956).

Correction equations based on measurement taken at maximum stream temperature and minimum flow is gotten using:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 \quad (6)$$

Where

Y=DOD, mg/l; X_1=BODs, mg/l; X_2=stream temperature; X_3=stream discharge, m^3/s; $b_0 b_1 b_2 b_3$ are constants derived from field parameters.

4. RESULTS

The sample collected from the Ntawaogba River was analysed. The mean data temperature at the time sampling was 28ºC. The results of the analysis of the physical, chemical and biological parameter are also presented in Table 1. Also present, was the results of the velocity, width, and depth measured and their respective averages.

Result obtained from Ntawaogba river was used to analyze the dissolved oxygen level at each sample point downstream with major pollutant sources which are open drains, domestic waste, slaughter waste, excretes.

Deoxygenating Rate Constant for Ntawaogba River was computed using the graphical method as shown in Fig. 4.

From the graph, the deoxygenating rate constant (K_1) was computed using equation 2 with slope 0.06 and intercept 0.54

K_1=0.26

Correction to temperature at 28°C using equation 4, deoxygenating rate constant (K_1)

$$K_1 = K_{20}\Theta^{(T-20)} \quad (7)$$

K_1= 0.38 at 28°C

With an average velocity of the River (V) to be 0.37 and average depth of the river (H) which was 2.42m as stated in equation 5 the Reaeration Rate Constant (k_2)

$K_2 = 0.81d^{-1}$.

Correcting to temperature of 28°C at sampling time using

$$K_T = 0.81(1.024)^{(28.3-20)} \quad (8)$$

$K_2 = 0.98\ d^{-1}$ At 28^0 C

The self-purification factor f is

$$f = \frac{K_2}{K_1} = 2.55 \text{ for Ntawaogba River.} \quad (9)$$

Table 1. Velocity, width, and depth measurement

Sample point	Distance (m)	Time (s)	Velocity(m/s)	Depth(m)	Width(m)
Point A (Control)	100	270	0.37	2.44	12
Point B	100	280	0.36	2.23	11
Point C	100	290	0.34	1.98	14
Point D	100	275	0.36	2.26	12
Point E	100	260	0.38	3.10	10
Point F	100	285	0.35	1.80	9
Point G	100	240	0.42	3.50	11
Point H	100	250	0.40	2.50	12
Point I	100	260	0.38	2.60	14
Point J	100	270	0.37	1.85	16
Mean		268	0.37	2.42	12.1

From measurements, the average velocity, width and depth of the water are:
Average velocity = 0.37 m/s; Average depth = 2.42 m; Average width = 12.1 m

Table 2. Field data analysis for Ntawagba River

Parameters	Point A	Point B	Point C	Point D	Point E	Point F	Point G	Point H	Point I	Point J	FMEnv standard
pH	7.19	6.89	7.51	6.54	6.64	6.83	6.55	6.77	6.8	6.67	6.5-8.5
Temperature. ^oC	28.3	28	28.6	28.7	27.5	28.7	27	27.89	28.6	26.9	20-30
Electrical Conductivity, µS/cm	207	211	203	210	211	212	213	159	160	175	100
TDS (mg/l)	110	112	108	111	112	112	113	84	85	93	250
Turbidity, (NTU)	3	2	3	1	2	5	3	3	4	3	5
TSS (mg/l)	9	7	11	4	7	11	9	19	6	11	10
Dissolve Oxygen (mg/l)	5.6	4.97	4.84	3.65	5.03	3.89	4.73	4.93	5.12	4.86	7.2
BOD, (mg/l)	4.4	8.2	8.55	9.12	8.11	9.65	8.26	7.89	7.52	8.30	<10
COD, (mg/l)	12.35	14.42	14.62	15.76	14.11	15.26	15.03	13.75	12.38	14.25	5
Salinity (as Cl) (mg/l)	28.36	31.91	24.82	28.36	21.27	24.82	24.82	21.27	28.36	21.27	<2000
Nitrate, (mg/l)	1.869	1.869	1.913	1.978	1.848	1.826	1.869	2.195	1.978	1.482	50
Sulphate, (mg/l)	4.7	5.334	5.334	5.017	5.228	6.017	5.595	4.011	5.817	6.228	150
Phosphate, (mg/l)	1.664	1.419	1.313	1.672	1.558	1.504	1.648	1.439	1.873	1.538	0.3
Ammonia (mg/l)	5.216	4.398	3.381	4.888	4.782	5.1	4.846	3.276	3.381	4.782	<2
THC, (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1
Copper, (mg/l)	0.033	0.053	0.064	0.041	0.056	0.045	0.062	0.059	0.078	0.033	-
Zinc, (mg/l)	0.024	0.032	0.041	0.036	0.03	0.039	0.051	0.084	0.041	0.042	
Total Iron, (mg/l)	0.558	0.651	0.495	0.713	0.718	0.682	0.776	1.461	0.713	0.651	20
Manganese, (mg/l)	0.019	0.028	0.026	0.028	0.025	0.019	0.019	0.028	0.026	0.028	150
Lead, (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.1
THB $x10^4$ CFU/ml	3.1	1.7	3.5	2.3	1.6	2.8	3.6	2.3	1.8	2	-
TF $x10^2$ CFU/ml	0.9	0.3	1.1	0.4	0.6	1	1.2	0.8	0.4	0.6	10
TF $x10^2$	0.9	0.3	1.1	0.4	0.6	1	1.2	0.8	0.4	0.6	-

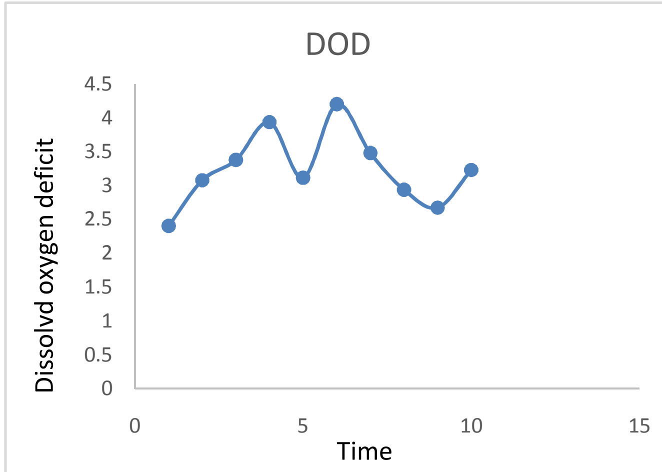

Fig. 2. Plot of dissolved oxygen deficit against time

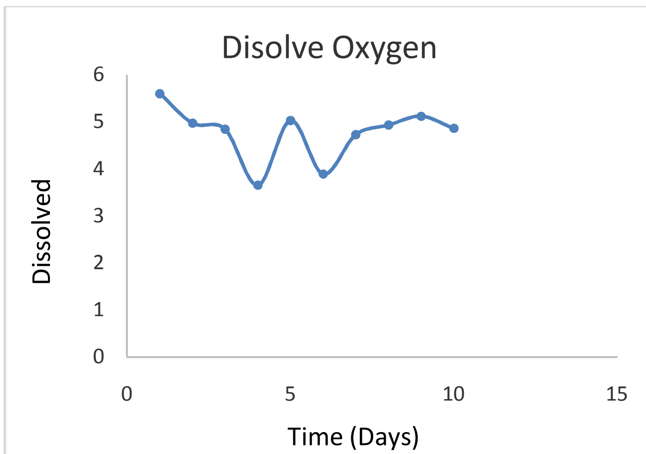

Fig. 3. Plot of dissolved oxygen against time

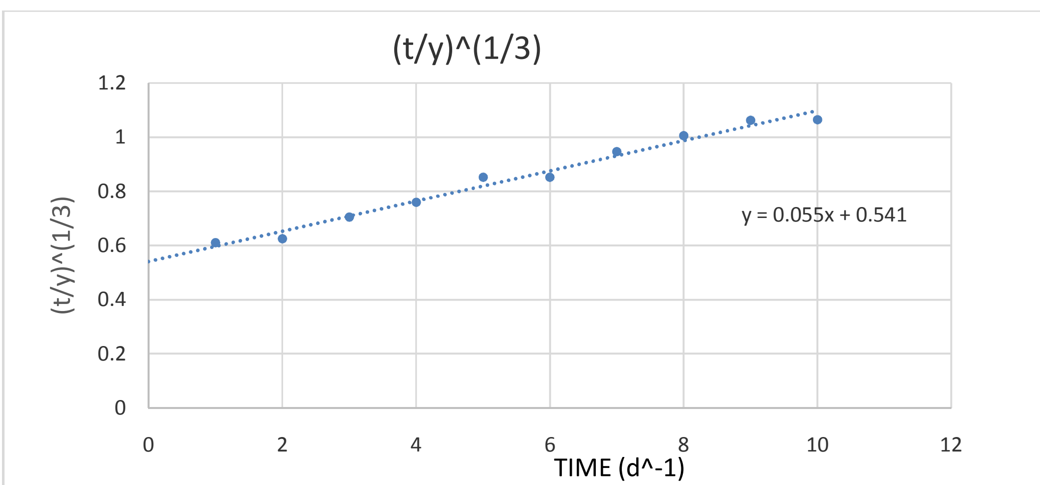

Fig. 4. Graphical determination of deoxygenating rate constant

Table 3. DOD measured and predicted value at different sample point

DO measured (mg/l)	DOD(mg/l)	BOD (mg/l)	Temperature	Flow Q(m3/s)	Predicted	sum.square
5.6	2.411	4.4	28.1	10.84	2.406304426	2.2048E-05
4.97	3.041	8.2	27.9	8.76	3.079904598	0.00151357
4.84	3.171	8.55	28.2	9.56	3.378774989	0.04317045
3.65	4.361	9.12	28	9.86	3.93820945	0.17875185
5.03	2.981	8.11	28	11.92	3.117579923	0.01865408
3.89	4.121	9.65	28.2	5.68	4.20275165	0.00668333
4.73	3.281	8.26	27.69	16.04	3.480871294	0.03994853
4.93	3.081	7.89	27.89	12.00	2.941325832	0.01950887
5.12	2.891	7.52	28	14.00	2.675578718	0.04640633
4.86	3.151	8.3	28.1	10.96	3.230691984	0.00635081
						0.36100987

Appropriate tool in Excel was used to generate the constant in the multiple regression model and was analyzed across the stream, considering the various parameters as stated in the table two. Result are tabulated in Table 3 and also represented in (Fig. 5).

As stated using multiple regression in equation 6;

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3$$

Where Y=DOD, mg/l; X_1=BODs, mg/l; X_2=stream temperature; X_3=Stream Discharge, m3/s; $b_0 b_1 b_2 b_3$ are constant derived from field parameters

b_o= 2.690293; b_1=0.89989; b_2=-0.16754; b_3=0.042823

$$Y = 2.690293 + 0.899899\ X_1 - 0.16754 + 0.042823X_3 \qquad (10)$$

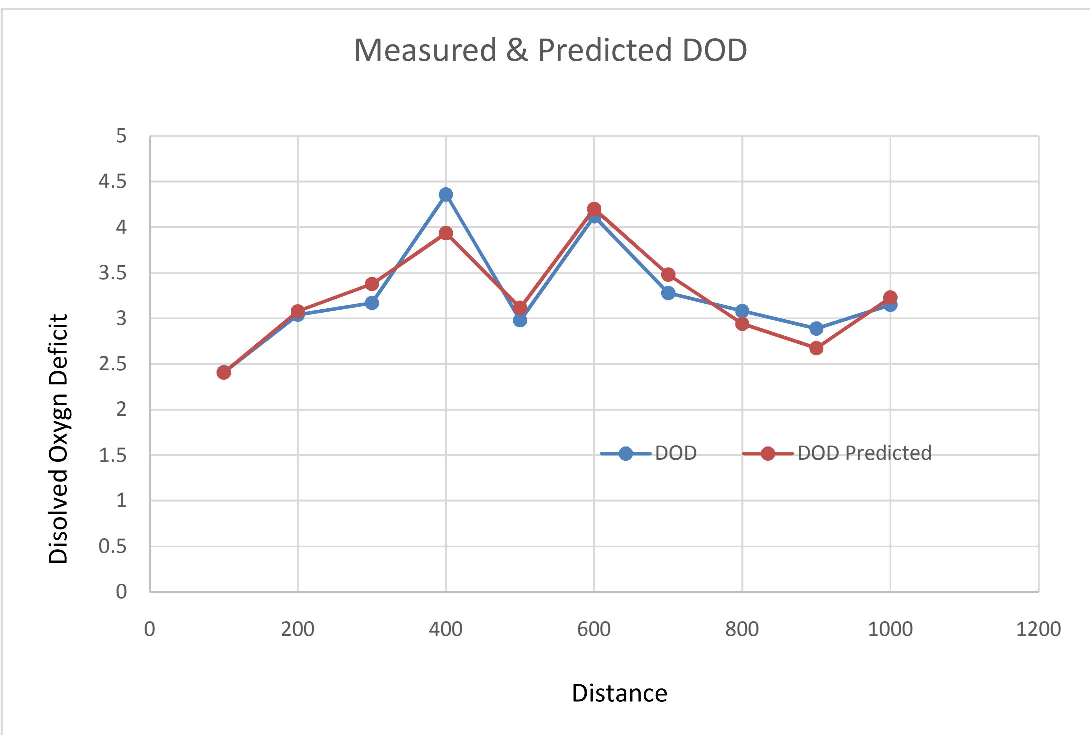

Fig. 5. Plot of DOD measured and predicted against distance

5. DISCUSSION

The analysis results on various physiochemical parameters for the various sample point, Water-quality analysis on the samples showed that most of the measured parameter falls within the recommended limit except for parameters like turbidity, BOD, COD, and DO in specific sample points (Table 2). High turbidity of river water is harmful because it provides hiding place for harmful microorganisms and such microbes can be consumed by people who drink such water thereby result in epidemics. High turbidity as observed in study river is unacceptable for aesthetic reasons [13]. Turbidity may reduce sunlight penetration into the water body thereby slowing down photosynthesis. Chemical parameters including BOD and COD higher than the maximum limits by Federal Ministry of Environment standards signified that there was high organic load in the river. Low DO as observed at some points may cause death of aquatics life. While ammonia above the recommended maximum limit of 2 mg/l, indicated that water is contaminated with sewage from continuous defecation along the stretch of the river. This basically fast tracked algae growth which subsequently degrade the water quality and result in eutrophication.

The field result indicated that there was a significant oxygen deficit at point 4 and 6 in Fig. 3, due to channel discharge, domestic waste, and slaughter waste discharge. The de-oxygenation rate constant (K_1) was calculated using equation 2 from BOD data and adjusted in accordance with the corresponding curves as presented in Fig. 4. Using the graphical method proposed by Thomas [14].

Using Microsoft excel based programme, the constant $b_0 b_1 b_2 b_3$ was generated for the regression model and was analysed across the stream considering the various parameters as stated in equation 6 and Table 3. Dissolved oxygen deficit predicted and measured against distance was plot and represented in Fig. 5.

The result of the analysis got from the field showed that the reaeration coefficient (K_2) under stream conditions was found to be 0.99. The deoxygenating constant (K_1) using the Thomas slope graphical method was computed to be 0.26. K_1 and K_2 were important parameters because they help select curve that best fit rivers conditions at the time and season of measurement. The river K_1 and K_2 values signified that the organic load into the river was high due to discharge of sewage, municipal and domestic waste. Also, the re-oxygenation co-efficient (f) of Ntawaogba river was 2.55. This indicated that the purifying capacity of the river system was low in relation to the received contaminants, though Ntawoagba river during the period of study falls under the typical values of receiving natural water body of large stream with moderate velocity [15].

Also, it was observed that the average river temperature was 28ºC. High temperature means increased oxidation, increase BOD exertion and increased rate of organic waste assimilation [16].

6. CONCLUSION

The combination of relatively low DO value which ranges from 3.65 to 5.6 along the river, high BOD and ammonia as observed in Ntawaogba river indicated that the river is polluted from multi source discharges (e.g storm water runoff, sewage, slaughter waste, municipal waste, domestic waste and untreated effluent) all loaded with organic matters.

The research enhanced the pollution dynamics of Ntawaogba river and therefore advised that proper environmental monitoring and water resource management should commenced by lead agencies in Port Harcourt, Rivers State of Nigeria to avoid further organic over load of the river which could increase the negative environmental impact of the river and increase the health risk of neighbouring communities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/25194