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Modeling of Dissolved Oxygen with Time in Urban Waterfront Using Reoxygenation and Deoxygenation Processes

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Abstract

The level of contamination in surface water has been a major concern to society in the reduction of oxygen in the water bodies. This study was carried out to test and validate a developed model of dissolved oxygen with time (days) in urban waterfronts. Water samples were collected at Bonny and Okirika waterfronts in Port Harcourt, Rivers State, Nigeria. This was taken at different times, depths, and distances along the river, in both dry and rainy seasons. The biological oxygen demand (BOD) and dissolved oxygen (DO) of the water samples were analyzed according to APHA-51210B. The model was validated by simulating the experimental results into the equation, and with coefficient determination (r^2). The results of the analysis showed that dissolved oxygen (DO) in the creeks in the presence of oxygen-consuming pollutants in the creeks depleted the DO concentration, which attained saturation after 30 days. The saturation with DO value approximately 7.2mg/l. however, from 80 to 100 days, deficit was almost insignificant with values recorded between $4.9x10^{-6}$mg/l and $3.5x10^{-6}$mg/l for the two creeks across the seasons. The experimental results were simulated into the prediction model. The developed model showed good agreement between measured and predicted results with high coefficient of determination. Thus, suggesting that the model be used for predicting dissolved oxygen with time in the waterfronts.

1. Introduction

Water is a key factor in the life of all living organisms and the sustainability of terrestrial and aquatic lives. Few issues have a greater effect on human life on the life of the planet than on the management of the most important natural resources. Natural resources are materials and substances that occur naturally and can be used for economic gain. [1] stated that water quality modelling as actually put in place as a scientific and technological base from which to formulate standardized consistent river water quality models and guidelines for implementation. Surface water models can be helpful tools because these tools simulate and predict the contaminant levels, distribution, and risk of chemical pollutants in the given water body [2]. This is because results from the models under different pollution scenarios are very important components of environmental impact assessment and they can give a basis and decision support for environmental management agencies to help them make right decisions.

Surface water modelling has long undergone a period of development since [3] developed the first water quality model to control river pollution in Ohio State of the U.S, ranging from single factor water quality to multi factors water quality; from steady- state model to dynamic model; from the point source to non-point source model; and from zero-, two-three dimensional models, of which more than 100 surface water quality models have been developed [1]. At the beginning stage (1925- 1965) BOD, DO as a bilinear system was developed one dimensional model applied to solve pollution issues in rivers and estuaries. Other notable model was that of Dobblins-Camp, which added two coefficients including rate of BOD caused by sediment release and surface runoff, and the model called Thomas equation which can be used to study the changing rate of DO control by algal photosynthesis [4].

One parameter that has significant effect on the characteristics of water is dissolved oxygen. It is required for the respiration of aerobic microorganisms as well as all other aerobic life forms. The actual quantity of oxygen that can be present in the solution is governed by the solubility, temperature, partial pressure of the atmosphere, and the concentration of impurities such as salinity and suspended solids in the water ([5]; [6]). Dissolved oxygen (DO) in surface water is influenced by several human activities, the more extensive the relevant sources and activities, the more likely the low DO will impair surface water ([7]). Constituents of wastewater effluents play an important role in the depletion of DO. The bacterial breakdown of organic solids present in wastewater and the oxidation of chemicals in it can consume much of dissolved oxygen in receiving water from bodies ([8]). This effect may be immediate, short-term, or extend for months or years as a result of build-up of oxygen-consuming substances in water ([9]).

Deoxygenation process is a chemical reaction involving the removal of oxygen atoms from a molecule, it also refers to the removal of molecular oxygen (O_2) from gases and solvents, deoxygenation (a decline in oxygen) occurs when oxygen in water is used up at a faster rate than it is replenished. Both warming and nutrient increase microbial consumption of oxygen, warming also reduces the supply of oxygen to the open ocean and coastal water by increasing the division into different layers or groups, and reducing the solubility of oxygen in water ([10]). Reoxygenation of water in order to balance the consumption of DO due to deoxygenation, atmosphere supplies O_2 to water and the process is called reoxygenation. The rate at which the oxygen is supplied by atmosphere to the polluted water depends upon the depth of the receiving water, deoxygenation rate is a process of oxygen reduction while the rate reoxygenation is the process of adding oxygen to the body of water ([11]). Effect of deoxygenation and insufficient oxygen alters behaviour of marine animals, including finfish and shellfish, thus the quality and quantity of habitat for economic and ecological important species is reduced. The decline in oxygen is not happening in isolation, at the same time food-webs are perturbed due to over fishing and physical perturbation, destruction of habitats and waters are getting warmer, more acidic, and experiencing higher nutrient loads ([12]).

The impacts of low dissolved oxygen levels include increase in disease, growth retardation, hampered swimming ability, alteration in feeding and migration, and of course, death of fish and other aquatic organisms. Long-term reduction in dissolved oxygen may result changes in species composition ([12]; [13]; [14]).

Oxygen demand, which may be in the form of BOD or COD, is the amount of oxygen used by microorganisms as they feed upon the organic solids in wastewater ([15]). The 5- day BOD (BOD_5) is the most widely used organic pollution parameter applied to wastewater. It involves the measurement of dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter. The presence of sufficient oxygen promotes the aerobic biological decomposition of organic waste ([6]). Although the BOD test is widely used, it has a number of limitations, which include the requirement for a high concentration of active microorganisms and the need for treatment when dealing with toxic wastes, thus reducing the effects of nitrifying organisms ([15]). The BOD measures only the biodegradable organics and requires a relatively long time to obtain test results, while the COD test measures the oxygen equivalent of organic material in wastewater that can be oxidized chemically ([15]; [6]). COD is always higher than BOD because COD measures substances that are both chemically and biologically oxidized ([5]). The ratio of COD to BOD provides a useful guide to the proportion of organic material present in wastewaters, although some polysaccharides, such as cellulose, can only be degraded anaerobically and so will not be included in the BOD estimation ([15]).

It has been reported by [16] that urban runoff pollution was heavier in the rainy and flood seasons, making COD high. [17] also reported that the value of BOD obtained during dry seasons was higher than during the wet season, which was due to the effect of temperature, salinity and putrefaction of substances deposited in the river. [18] in his study of numerical modelling of dissolved oxygen in an ultra-urban best management practice, showed a quick decrease in dissolved oxygen in Stormvalt during the dry season period which was attributed to exchange rate of dissolved oxygen air and water, the study also the decline of DO to total energy demand that was measured using COD methods to represent the materials consuming dissolved oxygen in the water column adding that light organic materials float on the water surface or attach to oil absorbent materials and generate a thin layer that consumes DO. The modelling of dissolved oxygen in Bonny/ Nembe, and Okirika/ marine base waterfronts in Port Harcourt LGA of Rivers State, Nigeria lack existing pieces of literature. Therefore, the need to model the dissolved oxygen in the area using oxygenation and deoxygenation is necessary. Hence, the aim of this study is to check validity of the model using experimental results from selected waterfront

2.0 Materials and Methods

2.1 Description of Study Area

Bonny/Nembe waterside is located on Lat 04º 45’25’’ N and Long. 07º 27 waterfronts receive wastewater from its metropolis, market, and dockyard of the Ibeto cement factory located 1.5km upstream of source point, discharge from clinical and domestic wastes, agricultural wastes from runoff, bunkering operations, with heavy soot from the local refining process of crude (kpo fire), and from the transportation of timber and other goods using speed boat, it also receives wastewater from the heavily dense creek road market were lots of buying and selling is done. The sampling point was located at Bonny/Nembe water side which is a jetty used as a ferry terminal for local transport and journeys outside Port Harcourt using petrol engine boats, which was also used as the control water body for the Bonny/Nembe waterfront (station 1). The creek road market is located beside the jetty.

Bonny/Nembe waterside in Port Harcourt is subject to human-induced pressures resulting from Industrialization, urbanization, and serious navigation, it links Port Harcourt city with the bonny island where most of the oil installations in Rivers State are situated. Hence, it is a hub for oil bunkering. It also links the island directly with the Atlantic Ocean through which crude oil is exported by massive oil tankers.

Station 2 is located at the Okirika/marine base waterfronts also in Port Harcourt LGA, It is also a jetty for local transportation to link neighboring Okirika, and other settlements and a hub for oil bunkering, it is a terminal where a lot of loading and offloading of crude is done, it also receives wastewater and runoff from lands and residential areas, the market around the waterfront and also have a deposit of soot because of the incomplete combustion from the several local refineries in the area, the control water body at Okirika/Marine base waterfront was sited close to the jetty.

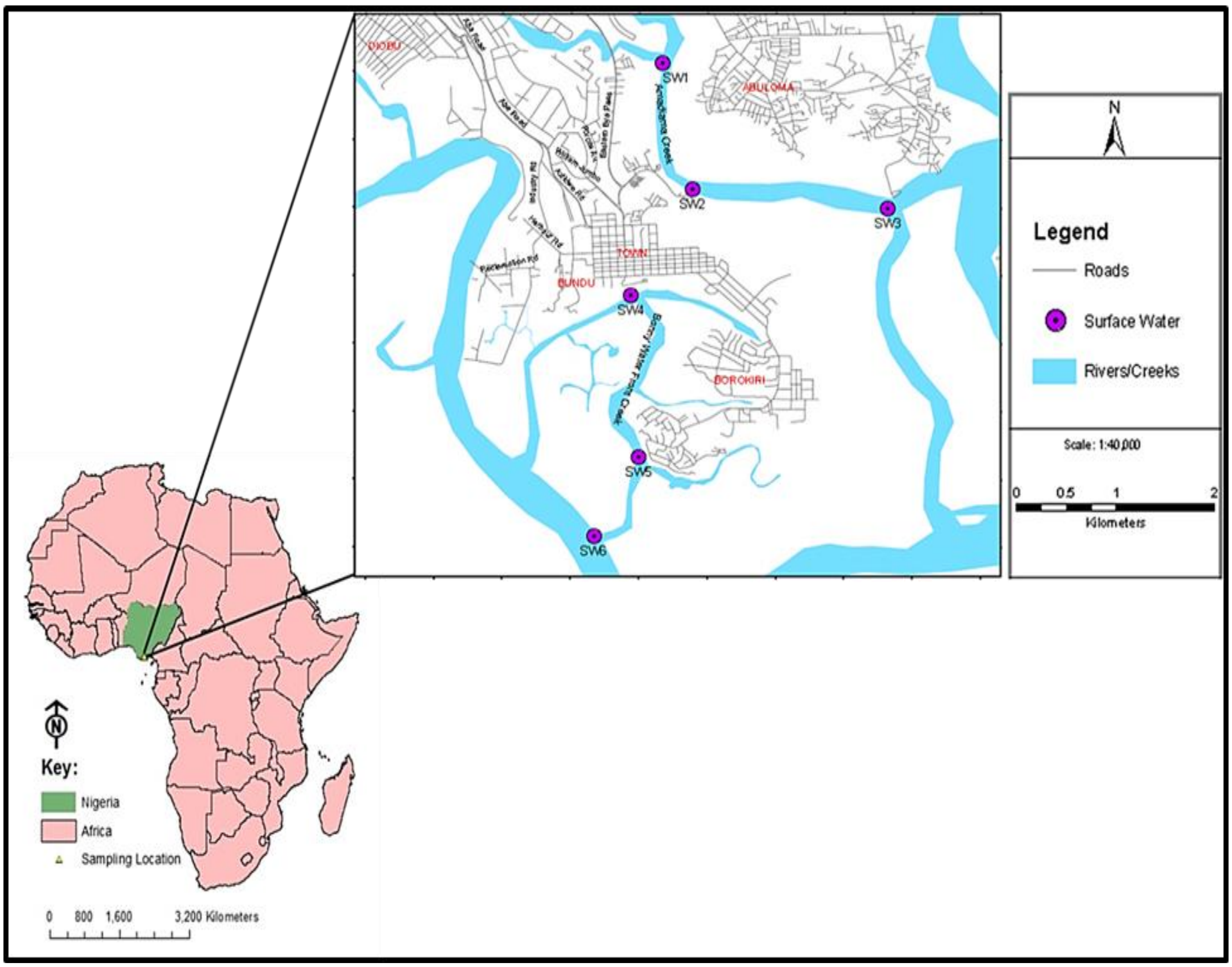

Figure 1: The Marine-Base Waterfront Bonny /Nembe waterfronts in Port Harcourt in the Niger Delta province, Nigeria

2.2 Survey/ Sample Collection and preparation

The materials that were used for the analysis included sample bottles, ropes, preservatives, tapes and marker pens, samplers/sampling equipment, syringe and needles, mercury in glass thermometers, sample storage/transit containers (coolers), ice packs amber glass with Teflon lined lid, pen/wax crayon, field notebook, pH meters, life jacket, gloves, rubber boots speed boat, cables chargers, and spare battery.

Figure 1 showed the points from where the water samples were collected in two seasons: the dry season (February 2019) and the wet season (July 2019) to ascertain the seasonal effect of waste discharge and other contaminants on the receiving rivers with respect to depth. Location 1(SW1) sample was taken at the jetty (the exact loading point with about 100 boats, leading to the tributary). From the waste discharge point, water samples were collected at intervals of 10 m up to 100 m (10, 20, 30, 40, 50, 60, 70, 80, 90, 100 m), and the depth was also measured from 10m to 100m away from the discharge point in the direction of water flow on the water surface in both rainy and dry seasons. The samples were collected in triplicates at each sampling point (SW1, SW2, SW3, SW4, SW5, and SW6 for BC and BWC waterfronts, respectively) with respect to their coordinates to reduce errors that may arise due to non-uniform distribution of the water properties (Table 1). Sample management was strictly in line with standard procedures ([19]).

The water samples collected were stored in plastic bottles, which were thoroughly washed with distilled water and rinsed with dilute nitric acid before use. The bottles containing water samples were placed in a cooler containing ice packs to protect against sunlight, and then taken to the laboratory for analysis to determine the physicochemical properties of the water samples. The first three sampling points covered the upstream while the last three sampling points covered the downstream region**.**

The depths were measured with a rope tied to a weight, the weight being let down to the bottom of the creek, marked, and held at the surface 0m, upon retrieval from the river a tape was used to measure from weight to marked point of the rope and depth in meter was recorded from 10m to 100m away from downstream, the survey and selection of sample locations are presented in table 4.

Table 1: Selection Points and Survey of Sample Location

Location	Point	Sample Code	Coordinate
Marine Base Creek (MBC)	**1**	SW1	N04^{0} 47′ 03.5″ E007^{0} 01′ 40.0″
	2	SW2	N04^{0} 46′ 07.8″ E007^{0} 01′ 53.4″
	3	SW3	N04^{0} 45′ 59.4″ E007^{0} 03′ 19.1″
Bonny Water Front Creek (BWFC)	**4**	SW4	N04^{0} 45′ 20.8″ E007^{0} 01′ 26.5″
	5	SW5	N04^{0} 44′ 09.4″ E007^{0} 01′ 30.1″
	6	SW	N04^{0} 43′ 34.5″ E007^{0} 01′ 10.3″

2.3 Determination of Biochemical Oxygen Demand (BOD)

The (BOD) was determined according to APHA-51210B, BOD. This was done by measuring the DO of the samples contained in a BOD bottle before and after five days of incubation at 200ºC. The BOD in sample was calculated using the formula

BOD = $(S_1-S_2) – (B_1-B_2)$ x % dilution.

Where:

S_1 = DO for the sample,

S_2 = DO after incubation of sample,

B_1 = DO for the first day for blank,

B_2 = DO after incubation for blank.

2.4 Dissolved Oxygen Modelling

The prediction of dissolved oxygen (DO) in the creeks was modeled using the popular developed model by [3]. According to Streeter and Phelps, the concentration of DO was based on two competing processes: namely deoxygenation and reoxygenation.

Case I: Deoxygenation

In deoxygenation, the rate of oxygen consumption depends on BOD content removed, which is expressed as:

$$r_1 = \frac{dL}{dt} = -k_1 L \quad (1)$$

where: $r_1 =$ Rate of deoxygenation (mg/l.day)

$k_1 =$ First order rate coefficient (day^{-1})

$L =$ Remaining BOD in water (mg/l)

$t =$ Time of deoxygenation (day)

Upon integration of equation (3.1) and simplifications, we obtained as follows:

$$\int_{L_o}^{L} \frac{dL}{L} = k_1 \int_0^t dt \quad (2)$$

$$L = L_o e^{-k_1 t} \quad (3)$$

where: $L_o =$ Ultimate BOD or initial concentration of BOD (mg/l)

Substituting equation (3) into equation (1) gives:

$$r_1 = \frac{dL}{dt} = -k_1 L_o e^{-k_1 t} \quad (4)$$

Case II: Reoxygenation

In reoxygenation, the rate of oxygen replenishment depends on DO deficit and reaeration rate coefficient, and this is expressed as:

$$r_2 = k_2 (C_s - C) = k_2 D \quad (5)$$

where: $r_2 =$ Rate of reaeration (mg/l.day)

$k_2 =$ reaeration rate coefficient (day^{-1})

$C_s =$ DO saturation (mg/l)

$C =$ Actual DO concentration (mg/l)

$D =$ DO deficit (mg/l)

However, the time rate of DO deficit was expressed according to Streeter and Phelps (1925) as

$$\frac{dD}{dt} = k_1 L - k_2 D \tag{6}$$

But the concentration of actual dissolved oxygen was generally expressed as

$$\frac{dC}{dt} = -k_1 L + k_2 D \tag{7}$$

If the rate of reaeration is constant, then, equation (5) becomes

$$D = C_s - C \tag{8}$$

And upon differentiating equation (8) at constant C_s gives

$$\frac{dD}{dt} = -\frac{dC}{dt} \tag{9}$$

Combining equations (3), (6) and (9) gives:

$$\frac{dD}{dt} = -\frac{dC}{dt} = k_1 L_o e^{-k_1 t} - k_2 D \tag{10}$$

Therefore, on re-arrangement, we have

$$\frac{dD}{dt} + k_2 D = k_1 L_o e^{-k_1 t} \tag{11}$$

Equation (11) is a non-linear ordinary differential equation, and its solution given as:

$$D_{(t)} = \frac{k_1 L_o}{k_2 - k_1}\left(e^{-k_1 t} - e^{-k_2 t}\right) + D_o e^{-k_1 t} \tag{12}$$

where: $D_{(t)} =$ O_2 deficit with time = $C_s - C_{(t)}$ (mg/l)

$D_o =$ Initial O_2 deficit (mg/l)

Therefore, from equations (9) and (12), the actual DO oxygen concentration is given as

$$C = C_s - \left[\frac{k_1 L_o}{k_2 - k_1}\left(e^{-k_1 t} - e^{-k_2 t}\right) + D_o e^{-k_1 t}\right] \tag{13}$$

Where:

C - Actual

From (Sincero & Sincero,), at 20 ºC and 40 ºC, DO saturation was given as 9.0 mg/l and 6.0 mg/l respectively. Hence, at average creek temperature of 28 ºC, the DO saturation can be interpolated as:

$$C_{s(28^o C)} = C_{s(20^o C)} + \left(\frac{28-20}{40-20}\right) \times \left(C_{s(40^o C)} - C_{s(20^o C)}\right) \tag{14}$$

Therefore, DO saturation at average temperature of 28 ºC is calculated as:

$$C_{s(28^o C)} = 6 + \left(\frac{8}{20}\right) \times 3 = 7.2 \text{ mg/l} \tag{15}$$

The values of the constants k_1 and k_2 were obtained from [1] as 0.34 and 0.20 day^{-1} respectively. This model was validated by simulating the experimental results of the waterfronts during rainy and dry seasons into the equation, and also the coefficient of determination (r^2) (equation 16) to check the goodness of fit. The prediction ability of the model was evaluated on the bases of the root-mean-square-error (RMSE) (equation 17), and residual prediction deviation (equation 18).

$$r^2 = \left[\frac{\sum_{i=1}^{n}(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i-\bar{X})^2 \ \sum_{i=1}^{n}(Y_i-\bar{Y})^2}}\right]^2 \quad (16)$$

$$RMSE = \sqrt{\sum_{i=1}^{n}\frac{(Y_i-X_i)^2}{n}} \quad (17)$$

Where:
n = number of samples
Y_i= predicted ith values,
X_i= measured ith values

$$RPD = \frac{SD}{RMSE} \quad (18)$$

Where:
SD = standard deviation of the measured experimental data.
Model prediction ability was described as excellent if RPD > 2.0, almost good if 1.4 RPD < 2.0, and unreliable if RPD < 1.4 ([20]).

3.0 Results and Discussion

The laboratory test results of the dry and rainy seasons analysis carried out in the months of February and July, 2019, respectively are presented in Table 2. From the results, it was observed that there were variations between the dry and the rainy season in the Marine base creek and Bonny waterfront respectively. The DO ranged from 4.21 to 4.32 mg/l for both dry and rainy seasons which is below the allowable limit of World Health Organization (WHO). This suggesting that the DO of the both water fronts are acceptable within the prescribed standard. The BOD ranged from 6.93 to 9.043 mg/l for both dry and rainy season which is above the allowable limit of World Health Organization (WHO). This suggesting that the BOD of the both water fronts are not acceptable within the prescribed standard.

Table 2: Mean Results of the Laboratory Test

Parameter	**Marine Base Creek (MBC)**		**Bonny Water Front Creek (BWFC)**		**WHO Limit**
	Dry Season	Rainy Season	Dry Season	Rainy Season	
DO (mg/l)	4.27±0.32	4.32±0.37	4.29±0.10	4.21±0.09	5.0-7.0
BOD (mg/l)	9.043±0.61	6.93±0.33	18.07±0.04	7.10±0.22	4.0

3.1 Dissolved Oxygen Analysis

The deficit and the actual DO concentrations over time using the measured concentrations of BOD and DO (Table 2) as reference points with world health organization (WHO). The DO results are shown in Figures 2 to 5.

Table 3: Analysis of Dissolved Oxygen in the Creeks

Time (Days)	DS-MBC (mg/l)	RS-MBC (mg/l)	DS-BWFC (mg/l)	RS-BWFC (mg/l)
0	2.93	2.88	2.90667	2.99333
5	2.3526	3.29396	0.83987	3.2397
10	4.81817	5.33981	2.58219	5.30232
15	6.21442	6.43835	5.25651	6.42136
20	6.81745	6.90568	6.44033	6.89884
25	7.05562	7.08915	6.91237	7.08652
30	7.14622	7.15875	7.09269	7.15776
40	7.19265	7.19437	7.18533	7.19423
50	7.199	7.19924	7.19801	7.19922
60	7.19987	7.1999	7.19973	7.19989
80	7.2	7.2	7.2	7.2
100	7.2	7.2	7.2	7.2

Figures 2 and 3 show the concentration profiles of DO in the Marine Base and Bonny Water Front creeks, respectively. From the figures 2 and 3, the concentration of DO decrease from its initial concentration at the discharge point with time, and then increased thereafter. For instance, in Marine Base creek, DO initially decreased rapidly after 5 days to 2.3526 mg/l, and then increased up to 6.81745 mg/l in 20 days. After 20 days, DO increase seemed to be insignificant (6.81745 mg/l a – 7.2 mg/l), which can be described as the saturation points. The initial drop in DO concentration within the first 5 days was due to the high concentrations of carbonaceous and nitrogenous biological oxygen demand (CBOD and NBOD) recorded in the creeks, which consumes oxygen available. It has been reported that increase in BOD decreases DO concentration, and this puts aquatic lives in danger ([21]; [1]; [22]). In another report, the changing rate of DO was attributed to algal photosynthesis, which requires oxygen [4]. However, if there was no re-pollution, it was stated that as time and distance downstream increases, the concentrations of CBOD and NBOD are used up, and with continuous reaeration from the atmosphere, the DO in streams will build up again ([1]). Hence, the increase in DO as shown in the figures after 5 days implied that the level of BOD decreased with time.

On comparison, the concentration of DO was more depleted in Bonny Water front creek than in Marine Base. Meanwhile, both creeks exhibited same behaviour as the concentration of DO attained stability (saturation point) after 20 days the in two creeks. Also, the DO in dry season was higher compared to the rainy season. [22] also observed no significant difference in level DO in their study on variation of physicochemical properties of two rivers in the same season. Seasonally, Gogoi and coworkers reported the same variation in concentrations of DO in Subansiri River Basin Assam, India obtained from different months in dry and rainy seasons ([23]).

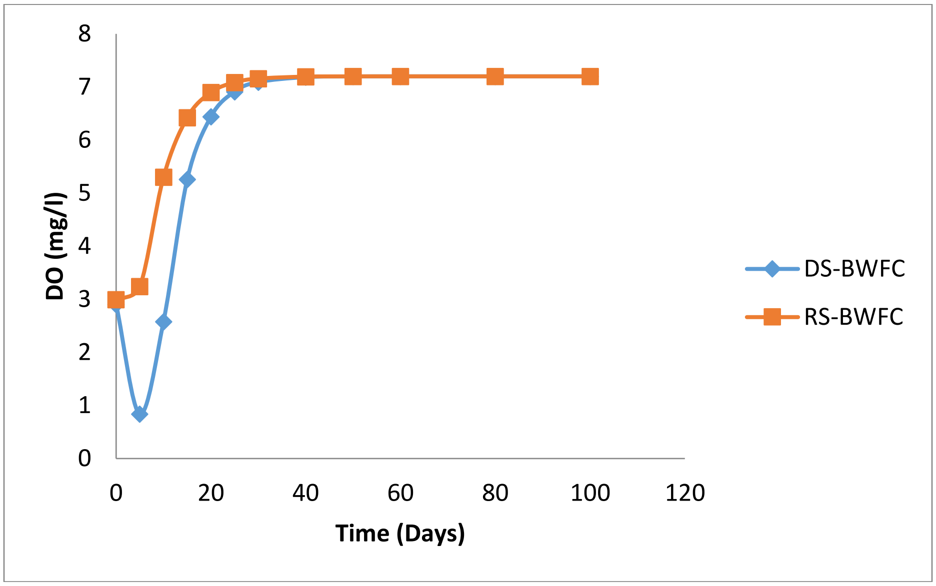

Figure 2: Variation of DO in Marine Base Creek

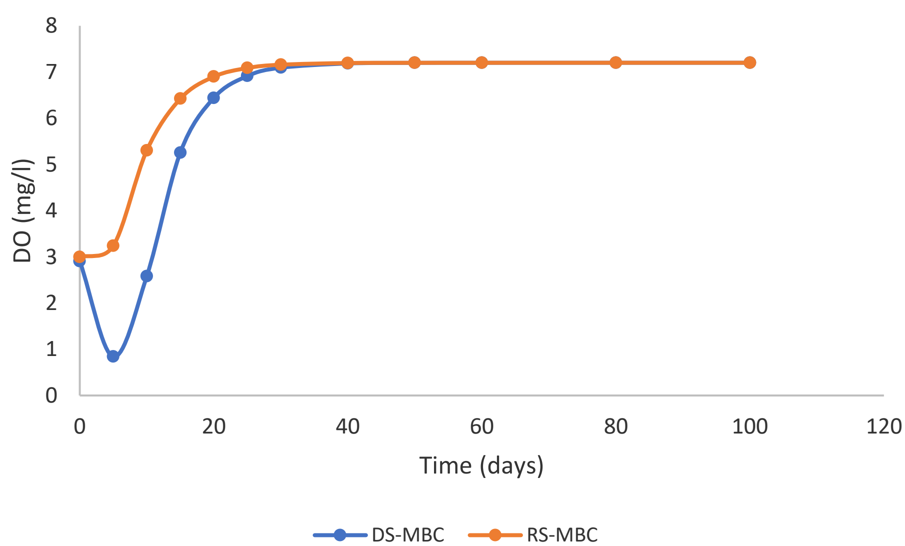

Figure 3: Variation of DO in Bonny Waterfront Creek

3.2 DO Deficit in Marine Base and Bonny Water Front Creeks

Figures 4 and 5 show the concentration profiles of DO deficit in Marine Base and Bonny Water Front creeks for dry and rainy seasons, respectively. As shown in the figures, the DO deficit increased rapidly within 5 days, and then decreased continuously with time. Again, in Marine Base creek, DO deficit increase after 5 days was to 4.8474 mg/l from the initial 4.27 mg. The DO deficit after 5 days decreased as time increases and was almost completely depleted after 80 to 100 days (2.5×10^{-6} to 4.5×10^{-8} mg/l). The initial increase in DO deficit has been explained in the work of [1]. Hence, according to [1], when there is a high concentration of the source of oxygen consuming pollutant in rivers or streams, DO consumption will initially increase at faster rate near the point of waste discharge, and thereafter decreases, which in most case complete depletion of DO may be experienced.

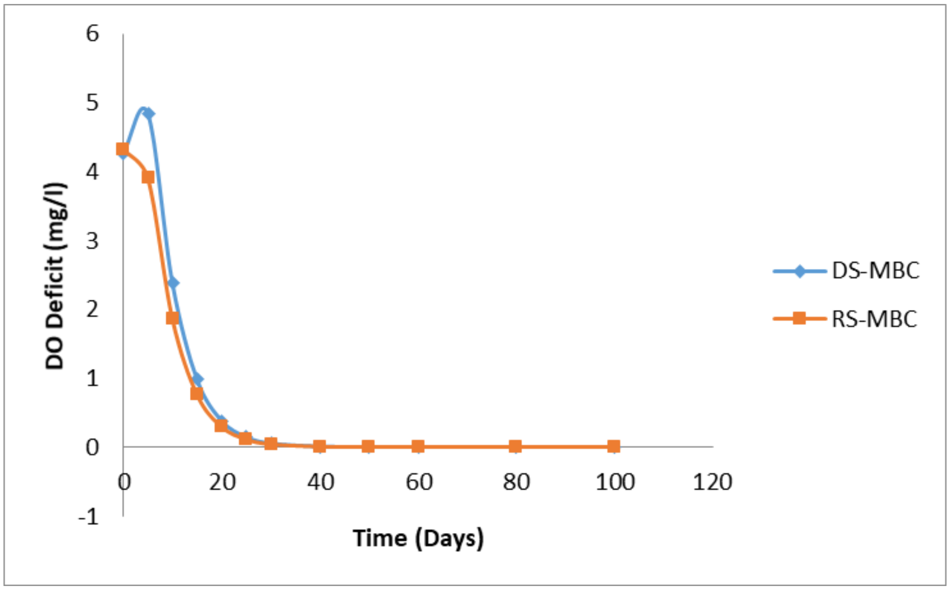

Figure 4: DO Deficit in Marine Base Creek

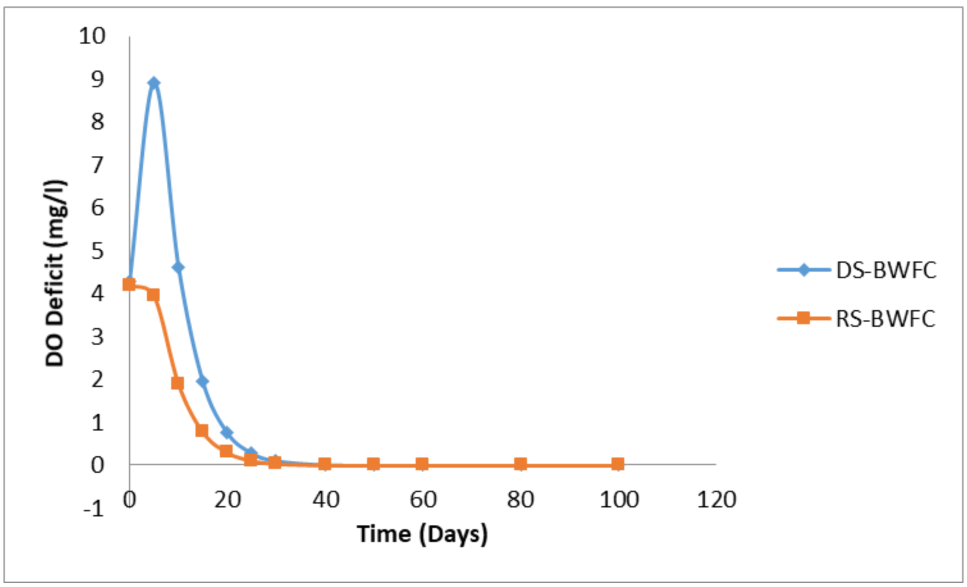

Figure 5: DO Deficit in Bonny Water Front Creek

3.3 Validation of the Model

The real fact of a developed model for solving a particular problem depends on its predictions and validation. The results of the developed dissolved oxygen model for Bonny and Marine Base Waterfront during dry and rainy seasons were obtained by substitution of the results of a number of measured data into the model. These were compared to ascertain the predictability of the model. The predicted results of the dissolved oxygen deficit of the waterfronts during dry and rainy seasons were presented in Table 4. Figures 6 to 9 show the graphical relationship between measured and predicted dissolved oxygen values using standard operation procedures. It was observed that the model has a high relationship with measured data from the waterfronts with a coefficient of determination (r^2) value of 1 for Marine base waterfront during dry and rainy season, Bonny waterfront during rainy season, and also 0.9623 for Bonny waterfront during dry season, respectively. Also, average RMSE of 6.0531, 6.1160, 6.2307, and 6.1047 achieved in the current study which show that the errors were minimal. In addition, average RPD values of 3.205, 3.249, 2.89, and 3.26 for the Marine base waterfront and Bonny waterfront during the dry and rainy season, respectively. With the RPD values of 3.205, 3.249, 2.89, and 3.26, the model prediction ability can be described as excellent. This pointed out that the model can express the experimental results precisely.

Table 4: Predicted Dissolved Oxygen Deficit in the Creeks

Time (Days)	DS-MBC (mg/l)	RS-MBC (mg/l)	DS-BWFC (mg/l)	RS-BWFC (mg/l)
0	4.27	4.32	4.29333	4.20667
5	4.8474	3.90604	8.91151	3.9603
10	2.38183	1.86019	4.61781	1.89768
15	0.98558	0.76165	1.94349	0.77864
20	0.38255	0.29432	0.75967	0.30116
25	0.14438	0.11085	0.28763	0.11348
30	0.05378	0.04125	0.10731	0.04224
40	0.00735	0.00563	0.01467	0.00577
50	0.001	0.00076	0.00199	0.00078
60	0.00013	0.0001	0.00027	0.00011
80	2.50E-06	1.90E-06	4.90E-06	1.90E-06
100	4.50E-08	3.50E-08	9.00E-08	3.60E-08

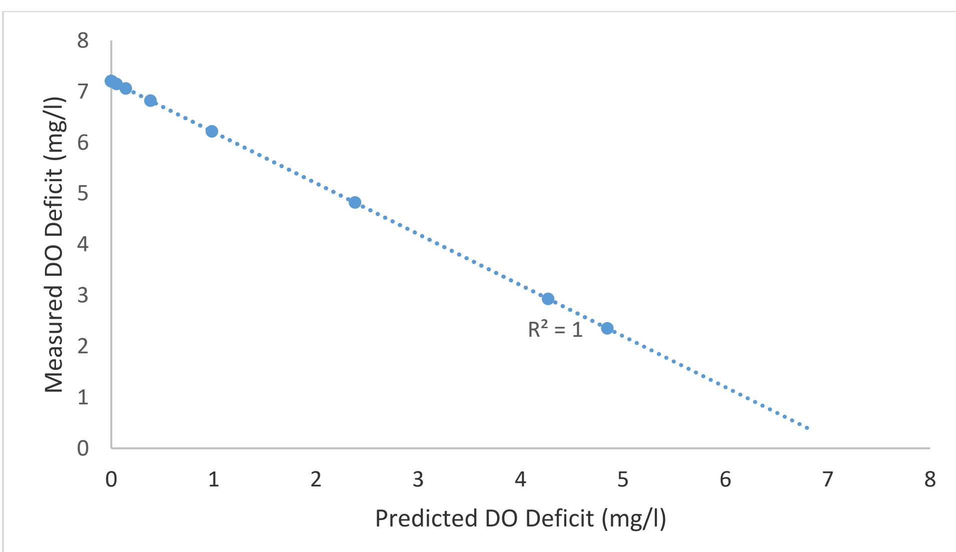

Figure 6: Measured and Predicted DO Deficit (mg/l) for Dry Season Marine Base Water Front

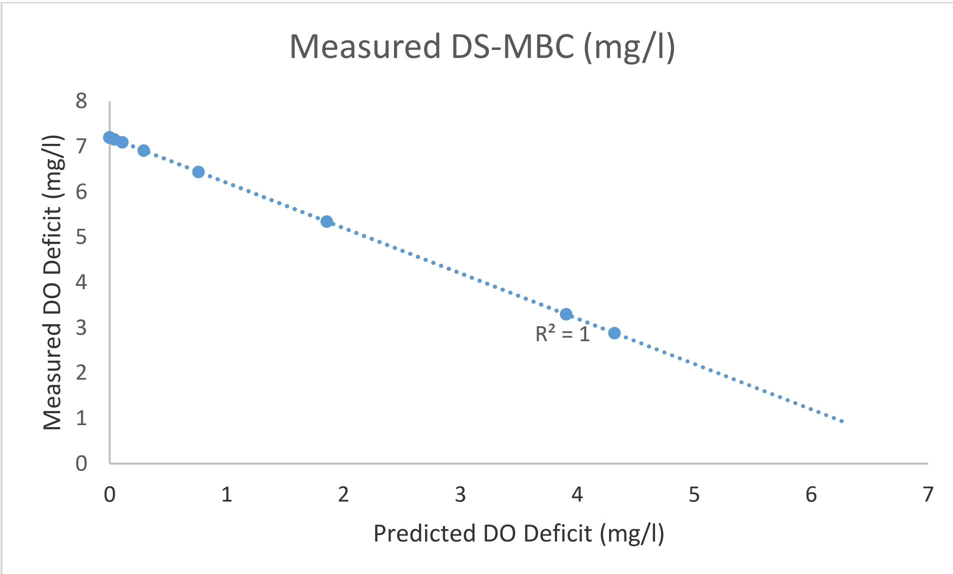

Figure 7: Measured and Predicted DO Deficit (mg/l) for Rainy Season Marine Base Water Front

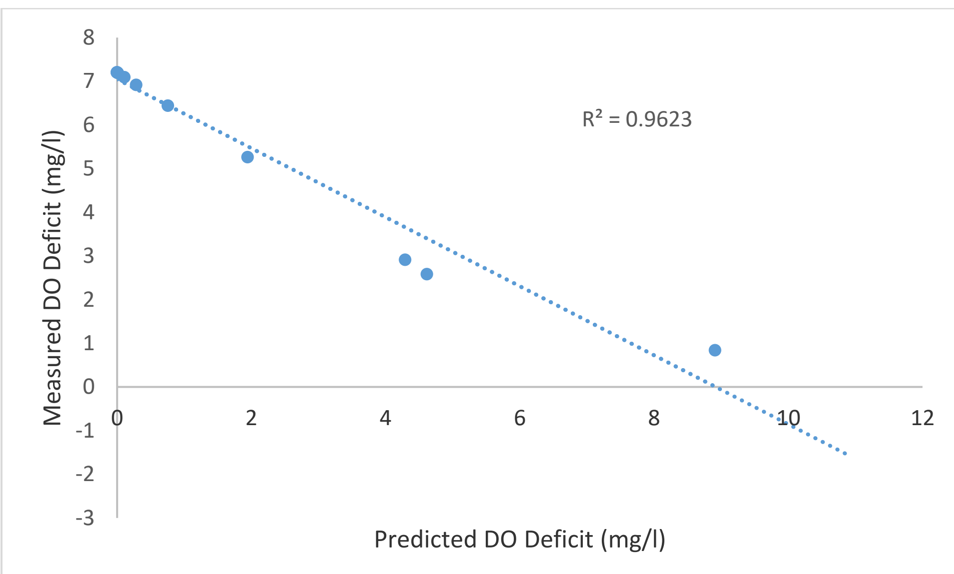

Figure 8: Measured and Predicted DO Deficit (mg/l) for Dry Season Bonny Waterfront

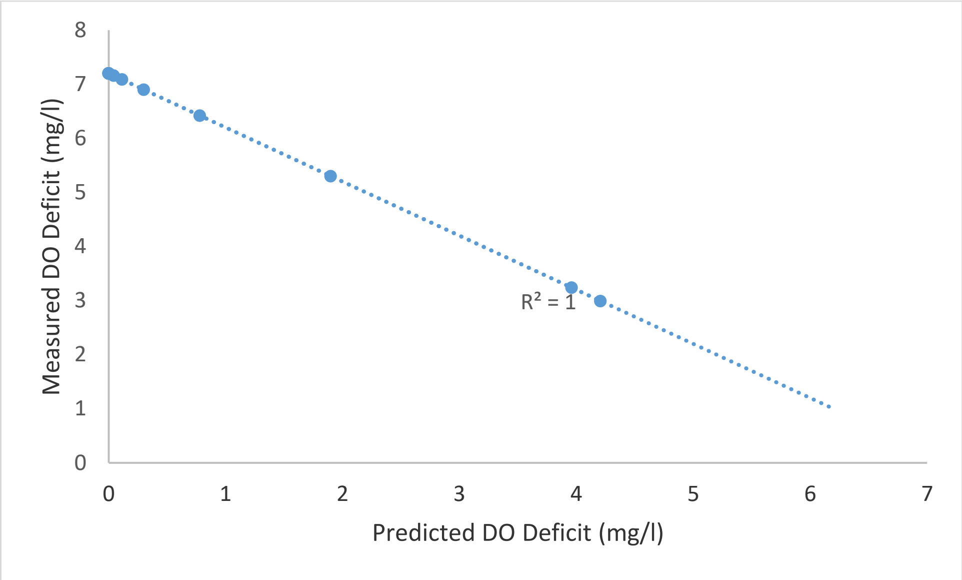

Figure 9: Measured and Predicted DO Deficit (mg/l) for Rainy Season Bonny Waterfront

4.0 Conclusion

This study had simulated and validated dissolved oxygen developed predictive model for Marine Base and Bonny waterfronts to ensure prediction of dissolved oxygen with time. The following conclusions were drawn from the results obtained:

i. The results of the analysis shows that dissolved oxygen (DO) in the creeks in the presence of oxygen consuming pollutants in the creeks depleted the DO concentration, which attained saturation after 30 days.
ii. Results obtained show that DO deficit after 5 days decreased as time increases and was almost completely depleted after 80 to 100 days ranging from 4.5×10^{-8} to 2.5×10^{-6} mg/l) for the two creeks across the seasons.
iii. Model prediction achieved in this study can be categorized as almost good for high coefficient of determination (r^2), minima RMSE, and average RPD values of 3.21, 3.25, 2.89, and 3.26. These show the potential of the model to predict DO in Marine base waterfront and Bonny waterfront, respectively.

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