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Development of Mathematical Model to Predict Exponential Growth of E-Coli Influenced by Heterogeneous Velocity and Oxygen Deficit in Onu-Imo Creek

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ABSTRACT

This paper investigates and evaluates the predominant parameters of influence on the depositions and migration process of E.coli in Onu- Imo River. The study monitored the behaviour of the contaminant based on their rates of deposition at different waste discharge point in the study environment, oxygen deficit were considered to be an influential parameter to evaluated its effect on the transport system, the trend shows the rates of impact from oxygen deficits in terms of heterogeneous growth rates in the River, since E.coli grows well in aerobic and anaerobic conditions, there rate of growth were evaluated, this condition explained the heterogeneity in growth rates based on these factors, because some stations point experienced variation of oxygen deficit in the marine environment, such facultative microbes reflected its rates of heterogeneity in oxygen deficit, as it is reflected in the trends. This implies that the migrations of the contaminant reflects its behiviour based on this factors, the study were able to evaluated the velocity of flow at heterogeneous state, the River flow velocity also developed some level of impacts, this were observed from their flow evaluation that developed some level of heterogeneous in some station point and predicted values, these parameters were monitored and it was observed that there is high rate of impact on their rates of concentration in the marine environment, the variation of some micro-element also expressed their impact on the growth rate, but reflected heterogeneity in their influence. The study has expressed the rate of these two parameters impact on the migration of E.coli in Onu- Imo River, the study is imperative because E.coli causes gastrointestinal illness, skin ear respiratory neurologic and wound infections, the most commonly reported are stomach cramp, diarrhea, nausea vomiting and low-grade fever. The rate of E.coli deposition has been monitored, these results can be applied for scientific assessment of the river in-line with the rate of pollution, the study can be applied to design a treatment, so that the water from the River can be applied for domestic use The predictive were subjected to simulation; these were compared with experimental Values, and both parameters developed best fits correlation.

Keywords: *Mathematical Model, E.coli, Heterogeneous velocity and oxygen deficit*

INTRODUCTION

Experts have stated that E. colial so grows anaerobically (in the absence of oxygen). However, unlike a quantity of anaerobic bacteria such as E. coli also grows fine in aerobic environments, these are normally culture flask in a laboratory Eluozo and Ezeilo 2018a, Eluozo and Ezeilo 2018b) (. E. coli is a facultative aerobe. It implies that such species of microbes can grow in environments with or without oxygen. In universal rule, a bacterium can be more efficiently in the application of its nutrients during aerobic growth, thus can develop more energy and grow faster (Eluozo and Ezeilo 2018cEluozo and Ezeilo 2018d). This type of microbes are known to cause diseases acquired from contact with contaminated water, it definitely cause gastrointestinal illness, skin, ear, respiratory, eye, neurologic, even wound infections. It has frequently been reported that it develop symptoms from such results such as stomach cramps, diarrhea, nausea, vomiting, including low-grade fever'.

The cause of infection by various bacteria, viruses, and protozoa are from Water borne diseases (i.e., diarrhea, gastrointestinal illness) these can be observed from various expert that has carried out studies on the outbreak such as contaminant (Craun et al., 2006Eluozo and Oba 2018a, Eluozo and Oba 2018b). In developing nation like Nigeria and other parts of Africa, it has been affected by various outbreak of waterborne diseases, these has definitely infect millions of people in Africa (Fenwick, 2006, Eluozo and Afiibor 2018, Eluozo and Afiibor 2019). Meanwhile, developed nation like the United States, it was observed in the year past that these diseases are a major cause of their illnesses. Research done by Craun et al. (2006, Eluozo and Amadi 2019a, Eluozo and Amadi 2019b) has statistically reported on waterborne outbreaks in the U.S., from the study it was observed that at least 1870 outbreaks (23 per year) occurred between 1920 and 2002.

A comparatively current report of the U.S. Environmental Protection Agency (EPA) has estimated that pathogens impair 480,000 km of Rivers and shorelines, while that of the lakes is2 million ha in U.S. (USEPA 2010a). It has been estimated that 900,000 illnesses and 900 deaths will take place in each year as reported in the U.S. These are due to exposure to water-borne pathogens (Arnone and Walling, 2007). More so, a cute gastroenteritis has been noted to be a major etiological agent, numerous microbes such as *Giarida Cryptosporadium*, *E. coli* O157:H7, *V. cholera*, and *Salmonella* were also observed to be the grounds for numerous outbreaks (Craun et al., 2006),While in the mid and later part of 18th century, diseases such as cholera, infected millions of people all over the world (Colwell, 1996Eluozo and Afiibor 2018).

Comparatively there are numerous current studies [for example Diffey (1991), Brookes et al. (2004), Jamieson et al. (2004), Gerba and Smith (2005), Gerba and McLeod (1976), John and Rose (2005), Hipsey et al. (2008), and Pachepsky and Shelton (2011)] these experts has definitely reviewed the latest state of art and its advancement in this field, precisely, for freshwater and estuarine sediments. However, there has been knowledge gap in these studies. Besides this, several latest reviewers are focused on specific water bodies, for example, John and Rose (2005) focuses on ground water, while Brookes (2004 Eluozo and Ezeilo 2018) focuses on reservoirs and lakes, and Jamieson et al. (2004Eluozo and Afiibor 2018 Eluozo and Oba 2018) focuses on agriculture watershed. Others, for instances is Kay et al. (2007) that also reviewed catchment on the dynamics of the microbes.

THEORETICAL BACKGROUND

Governing equation

$$\frac{dF}{dt} + A(x)U_X \;= B(x) \qquad (1)$$

Where F = contaminant growth rate in the River A_x and Ux =Bacterial transport coefficient, bulk density stream Velocity, oxygen deficit, while X= distance and time of transport, Period of Growth Rate, applying integrating factor, this equation can be write in this form

Applying integrating factor, we have the expression:

$$e\int u(t)dkt = e^{(t)kt} \;= e^{ukt} \qquad (2)$$

Multiplying equation [1] through by the integrating factor (I.F ℓ^{AE_x})

$$e^{A(x)U_x}\frac{dF}{dx} + A(x)U_x\, e^{A_xU_x} = B(x)e^{A_xU_x} \qquad (3)$$

$$\rightarrow \frac{dF}{dx}(A(x)U_x e^{uAx)U_x}) \;= B(x)e^{A(x)U_x} \qquad (4)$$

$$\left(Fe^{A(xU_x}\right) = \int B(x)e^{A(x)U_x} \qquad dx \qquad (5)$$

$$\rightarrow Fe^{A((x)Ux} \;= \int B(x)e^{u(x)} \qquad dx \qquad (6)$$

$$F = \ell^{-A(x)U_x}\,[\int B(x)\ell^{A(x)U_x}\; dx \qquad (7)$$

Applying integration by parts, where

U = B(x); du = B^1(x)

$$dv \;=\; e^{A(x)U_x}\; dx$$

$$V = \frac{\ell^{A(x)U_x}}{AU_x} \qquad (8)$$

$$\int B(t)e^{A(x)U_x}\,dt = \frac{A(x)e^{u(X)U_x}}{ukt} = \frac{1}{Au}\int e^{AUx}B^1\,d(x) \qquad (9)$$

Where u = $\ell^{AUx}\,dx$ =B(x)

dv = B^1(x)

du = Au$\ell^{AUx}\,dx$ = B(x)

du = $Au\ell^{Aux}\,dx$ = B(x)

So that the equation $\int B^1(x)\ell^{A(x)}dx$ in equation (9), is of this form

$$\int B^1(x)e^{Aux}dtx = B(x)e^{Aux} - \int B(x)Auxe^{Au^x}\,dx \qquad (10)$$

$$\int B(x)e^{Aux}\,dx = e^{-AUx}\int B(x)e^{A(x)ux}\,dx = B(x)e^{AUx} - Aux\int B(x)e^{Aux}\,dx \qquad (11)$$

$$e^{-Aux}\left\{B(x)e^{Aux} - \frac{1}{Aux}\int B^1e^{Auxt}\right\} = \ell^{-Aux}\left[\left\{Pe^{ukt} - \frac{1}{ukt}\right\}Pe^{ukt} - ukv\int P(t)e^{ukt}\,dt\right] \qquad (12)$$

$$\frac{e^{-Aux} Pe^{ukt}}{Aux} - \frac{Be^{-Aux} e^{Aux}}{Aux} - e^{-Auxt} \int Bx - Aux \int Be^{aUX} dx \quad (13)$$

$$\int B(X) e^{Aux} dtx = -e^{-Aux} \int Be^{Aux} dx + C \quad (14)$$

$$\ell^{-Aux}$$

$$\int B(x)\ell^{Aux} dx + \int B(x)\ell^{Aux} dx = C \quad (15)$$

$$B(x)e^{Aux} \; dx \; (1 + e^{-Aux}) = C \quad (16)$$

$$\mathrm{Bx}\,\ell^{Aux} \; dx\left(1 + \ell^{-Aux}\right) = \mathrm{C} \quad (17)$$

$$\int B(x)e^{Auxt} \; dx = \frac{C}{1 + e^{Aux}} \quad (18)$$

$$\int B(x) e^{Aux} \; dx = \frac{C}{1 + e^{-ukt}} \quad (19)$$

Now Substitute Equation (19) into equation (7), Gives

$$\mathrm{F}\,\ell^{Aux} = \int B(x)\ell^{Aux} dx \quad (20)$$

$$\mathrm{F} = \frac{Ce^{-ukt}}{1 + e^{-ukt}} \quad (21)$$

Materials and Method

Standard laboratory experiment where performed to monitor E.coli using the standard method for the experiment at different station, the water sample were collected in sequences base on specification stipulated at different locations, this samples collected at different location generated variations at different distance producing different E.coli concentration through physiochemical analysis, the experimental result were compared with the theoretical values for model validation

Results and Discussion

Table1. *Predictive and Experimental Values of E. coli Concentration at Different Distance*

Distance [x]	Predictive Concentration Variation Oxygen Deficit [150] [Mg/L] [C]	Experimental Values of Concentration Variation oxygen Deficit [150] [Mg/L]
2	115.6631621	132.316
4	131.5700933	134.06
6	137.8914062	135.732
8	141.2854508	137.332
10	143.4032788	138.86
12	144.8507931	140.316
14	145.9027531	141.7
16	146.7018051	143.012
18	147.3293668	144.252
20	147.8352953	145.42
22	148.2518285	146.516
24	148.6007368	147.54
32	149.5687577	150.916
34	149.7408957	151.58
36	149.8942401	152.172
38	150.0317095	152.692
40	150.1556478	153.14
42	150.2679589	153.516
44	150.3702059	153.82
48	150.5494732	154.212
50	150.6284864	154.3
52	150.7014952	154.316
54	150.7691591	154.26
56	150.8320443	154.132
58	150.8906398	153.932
60	150.94537	153.66
62	150.9966052	153.316
64	151.0446697	152.9
66	151.0898492	152.412
68	151.1323957	151.852

Table2. *Predictive and Experimental Values of E.coli Concentration at Different Distance*

Distance [x]	Predictive Concentration Variation Oxygen Deficit [110] [Mg/L] [C]	Experimental Values of Concentration Variation oxygen Deficit [110] [Mg/L]
2	105.1026467	109.414
4	108.3807869	109.712

6	109.5194198	109.994
8	110.0977554	110.26
10	110.4476979	110.51
12	110.6822314	110.744
14	110.8503661	110.962
16	110.9768027	111.164
18	111.0753418	111.35
20	111.1542993	111.52
22	111.2189843	111.674
24	111.2729461	111.812
32	111.4216113	112.204
34	111.4478876	112.262
36	111.4712547	112.304
38	111.4921704	112.33
40	111.5110013	112.34
42	111.5280442	112.334
44	111.5435423	112.312
48	111.5706743	112.22
50	111.5826166	112.15
52	111.5936425	112.064
54	111.6038536	111.962
56	111.613337	111.844
58	111.6221678	111.71
60	111.6304112	111.56
62	111.6381239	111.394
64	111.6453555	111.212
66	111.6521496	111.014
68	111.6585449	110.8

Table3. *Predictive and Experimental Values of E.coli Concentration at Different Distance*

Distance [x]	Predictive Concentration Variation Oxygen Deficit [100] [Mg/L] [C]	Experimental Values of Concentration Variation oxygen Deficit [100] [Mg/L]
	97.49217972	99.568
4	99.55164597	99.758
6	100.2576074	99.94
8	100.6143562	100.114
10	100.8296267	100.28
12	100.9736529	100.438
14	101.0767809	100.588
16	101.1542652	100.73
18	101.214613	100.864
20	101.2629431	100.99
22	101.3025203	101.108
24	101.3355249	101.218
32	101.4263985	101.578
34	101.442452	101.648
36	101.456726	101.71
38	101.4695009	101.764
40	101.481001	101.81
42	101.4914081	101.848
44	101.500871	101.878
48	101.5174353	101.914
50	101.5247253	101.92
52	101.5314555	101.918
54	101.5376879	101.908
56	101.5434758	101.89
58	101.5488652	101.864
60	101.5538958	101.83
62	101.5586023	101.788

64	101.563015	101.738
66	101.5671606	101.68
68	101.5710627	101.614
70	101.5747421	101.54

Table4. *Predictive and Experimental Values of E.coli Concentration at Different Distance*

Distance [x]	Predictive Concentration Variation Oxygen Deficit [95] [Mg/L] [C]	Experimental Values of Concentration Variation oxygen Deficit [95] [Mg/L]
2	93.31745015	80.396032
4	94.93759954	80.782256
6	95.49022369	81.168864
8	95.76895539	81.556048
10	95.93697684	81.944
12	96.04931906	82.332912
14	96.12972472	82.722976
16	96.19011737	83.114384
18	96.23714192	83.507328
20	96.27479468	83.902
22	96.3056234	84.298592
24	96.33132908	84.697296
32	96.40209053	86.317072
34	96.41458864	86.729216
36	96.42570079	87.144624
38	96.43564541	87.563488
40	96.44459732	87.986
42	96.4526981	88.412352
44	96.46006363	88.842736
48	96.47295601	89.716368
50	96.47862975	90.16
52	96.48386764	90.608432
54	96.48871805	91.061856
56	96.49322244	91.520464
58	96.49741655	91.984448
60	96.50133139	92.454
62	96.50499394	92.929312
64	96.50842784	93.410576
66	96.51165384	93.897984
68	96.51469028	94.391728
70	96.51755338	94.892

Table5. *Predictive and Experimental Values of E.coli Concentration at Different Distance*

Distance [x]	Predictive Concentration Variation Oxygen Deficit [90] [Mg/L] [C]	Experimental Values of Concentration Variation oxygen Deficit [90] [Mg/L]
2	88.95636682	89.80224
4	90.22483414	90.07392
6	90.65573391	90.31648
8	90.87273093	90.53136
10	91.00342849	90.72
12	91.09076926	90.88384
14	91.15325824	91.02432
16	91.20018126	91.14288
18	91.23671036	91.24096
20	91.26595472	91.32
22	91.28989587	91.38144
24	91.30985642	91.42672
32	91.36479298	91.47504
34	91.37449453	91.46112
36	91.38311986	91.43968
38	91.39083864	91.41216

40	91.39778666	91.38
42	91.40407387	91.34464
44	91.40979026	91.30752
48	91.41979568	91.23376
50	91.42419876	91.2
52	91.42826351	91.17024
54	91.4320275	91.14592
56	91.43552291	91.12848
58	91.43877749	91.11936
60	91.44181531	91.12
62	91.44465732	91.13184
64	91.44732187	91.15632
66	91.44982508	91.19488
68	91.45218116	91.24896
70	91.45440272	91.32

Table6. *Predictive and Experimental Values of E.coli Concentration at Different Distance*

Distance [x]	Predictive Concentration Variation Oxygen Deficit [88] [Mg/L] [C]	Experimental Values of Concentration Variation oxygen Deficit [88] [Mg/L]
2	87.16799918	89.45824
4	88.3166609	89.65592
6	88.70630519	89.79848
8	88.90241948	89.88936
10	89.02050484	89.93
12	89.09940285	89.92184
14	89.15584424	89.86632
16	89.19822224	89.76488
18	89.23121076	89.61896
20	89.25761916	89.43
22	89.27923766	89.19944
24	89.29726107	88.92872
32	89.34686301	87.47304
34	89.35562201	87.02312
36	89.36340924	86.54168
38	89.3703779	86.03016
40	89.37665063	85.49
42	89.38232671	84.92264
44	89.38748742	84.32952
48	89.39652008	83.07176
50	89.40049503	82.41
52	89.40416453	81.72824
54	89.40756248	81.02792
56	89.41071796	80.31048
58	89.41365601	79.57736
60	89.41639837	78.83
62	89.41896395	78.06984
64	89.42136932	77.29832
66	89.42362903	76.51688
68	89.42575592	75.72696
70	89.42776136	74.93

Table7. *Predictive and Experimental Values of E.coli Concentration at Different Distance*

Distance [x]	Predictive Concentration Variation Oxygen Deficit [85] [Mg/L] [C]	Experimental Values of Concentration Variation oxygen Deficit [85] [Mg/L]
2	84.4447541	85.11416
4	85.43317072	85.32528
6	85.76780498	85.51432
8	85.93610709	85.68224
10	86.03740578	85.83

12	86.10507102	85.95856
14	86.15346853	86.06888
16	86.18980239	86.16192
18	86.21808324	86.23864
20	86.2407213	86.3
22	86.25925218	86.34696
24	86.27470067	86.38048
32	86.31721257	86.39936
34	86.32471902	86.38008
36	86.33139251	86.35312
38	86.33736441	86.31944
40	86.34273982	86.28
42	86.34760387	86.23576
44	86.3520262	86.18768
48	86.35976638	86.08384
50	86.3631725	86.03
52	86.36631685	85.97616
54	86.36922848	85.92328
56	86.37193232	85.87232
58	86.37444984	85.82424
60	86.37679966	85.78
62	86.37899799	85.74056
64	86.38105902	85.70688
66	86.38299524	85.67992
68	86.38481764	85.66064
70	86.38653597	85.65

Table8. *Predictive and Experimental Values of E. coli Concentration at Different Distance*

Distance [x]	Predictive Concentration Variation Oxygen Deficit [80] [Mg/L] [C]	Experimental Values of Concentration Variation oxygen Deficit [80] [Mg/L]
2	79.81217813	79.18736
4	80.57865679	80.34808
6	80.83743169	80.49312
8	80.96744343	80.62344
10	81.0456514	80.74
12	81.09787404	80.84376
14	81.13521715	80.93568
16	81.16324705	81.01672
18	81.18506149	81.08784
20	81.20252148	81.15
22	81.21681251	81.20416
24	81.22872555	81.25128
32	81.26150443	81.38856
34	81.26729169	81.41488
36	81.2724366	81.43992
38	81.27704051	81.46464
40	81.28118446	81.49
42	81.28493412	81.51696
44	81.2883432	81.54648
48	81.29430978	81.61704
50	81.29693535	81.66
52	81.29935911	81.70936
54	81.30160345	81.76608
56	81.3036876	81.83112
58	81.30562811	81.90544
60	81.30743934	81.99
62	81.30913378	82.08576
64	81.31072239	82.19368
66	81.31221477	82.31472
68	81.31361942	82.44984
70	81.31494384	82.6

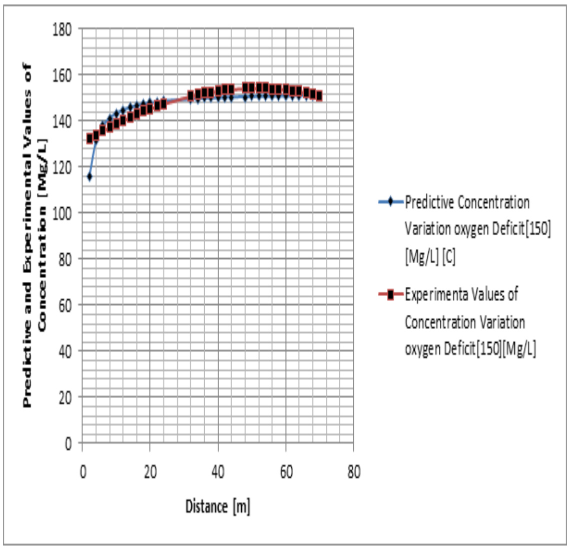

Figure1. *Predictive and Experimental Values of E. coli Concentration at Different Distance*

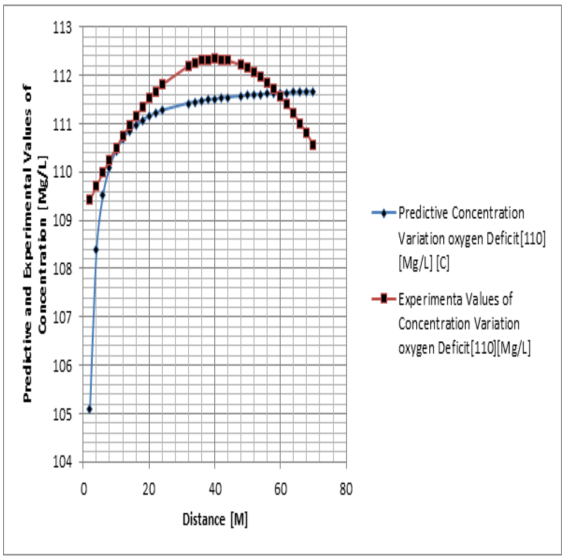

Figure2. *Predictive and Experimental Values of E. coli Concentration at Different Distance*

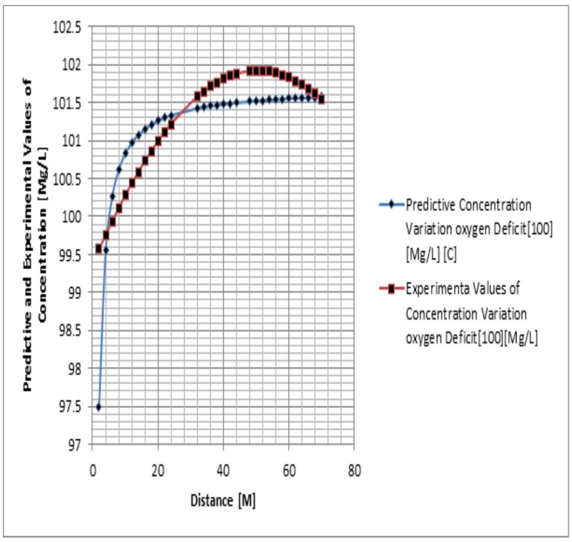

Figure3. *Predictive and Experimental Values of E.coli Concentration at Different Distance*

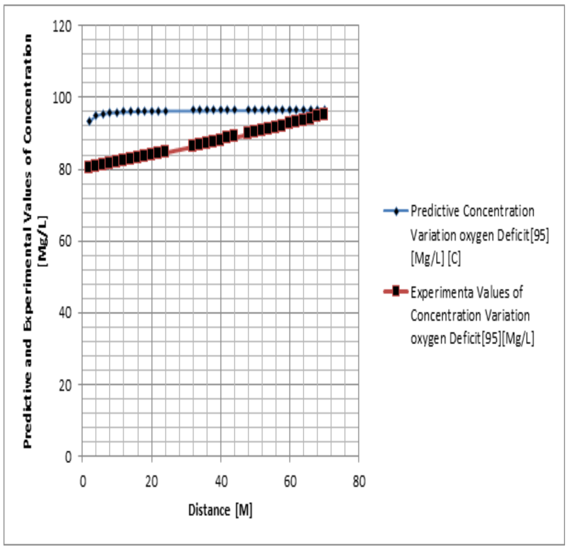

Figure4. *Predictive and Experimental Values of E. coli Concentration at Different Distance*

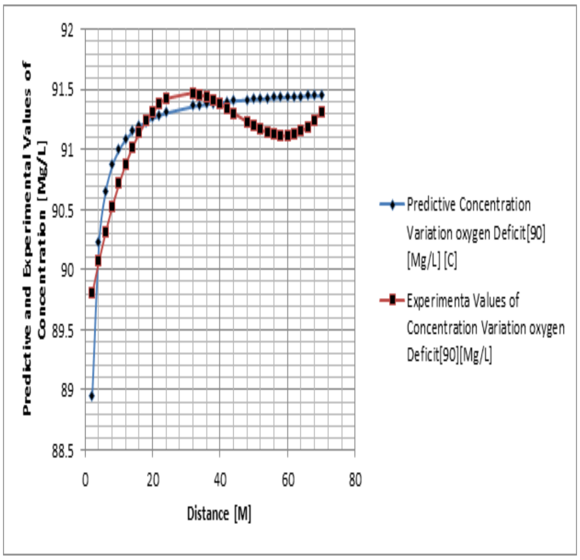

Figure5. *Predictive and Experimental Values of E. coli Concentration at Different Distance*

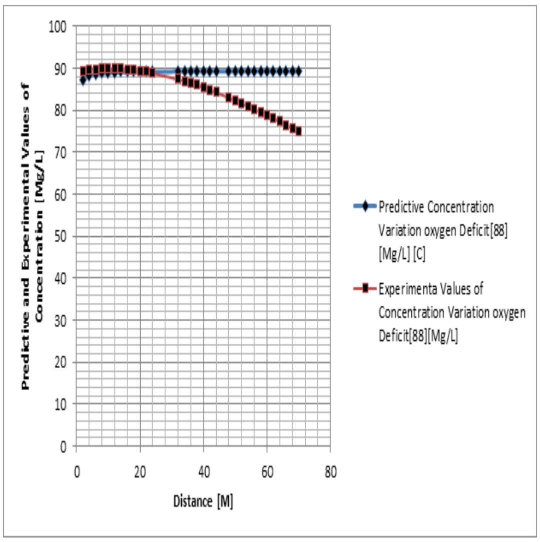

Figure6. *Predictive and Experimental Values of E.coli Concentration at Different Distance*

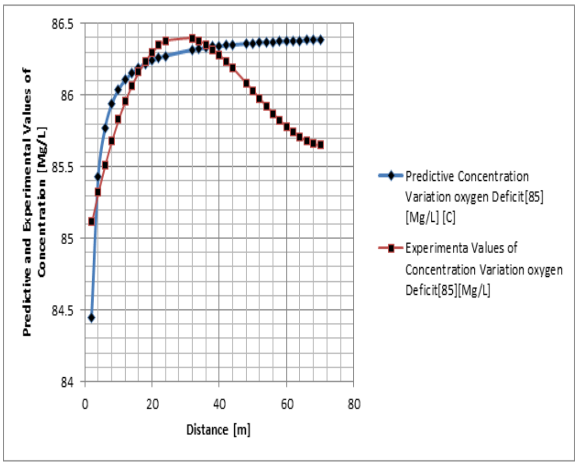

Figure7. *Predictive and Experimental Values of E.coli Concentration at Different Distance*

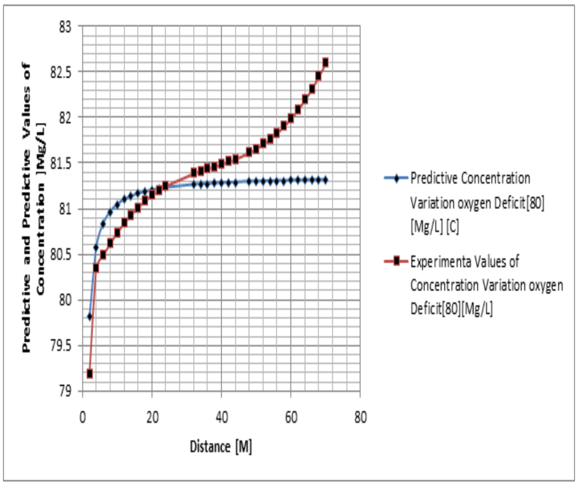

Figure8. *Predictive and Experimental Values of E. coli Concentration at Different Distance*

Figure one to eight express the growth rate of E.coli in the marine environment, the migration rates of the contaminant at the station point in the experimental date shows the fluctuation in the migration of the microbes in study environment. The behavior of the contaminant were considered in the study as the growth rate of the microbes and are been pressured by the oxygen deficit and velocity of the Rivers, the figures observed exponential growth rates in various station point, the initial concentration was observed to the point where the growth experienced gradual progressive increase to the optimum point recorded at distance of seventy metres away from start of observation. Fluctuation were experienced in most station point, similar condition were also observed in the predictive values, the pressure from the stated parameters were evaluated in the system monitoring the reflection in the growth rate of the microbes, these were in various station point and simulation values, but there are some variations in the growth rates were by the velocity of the River developed fluctuation thus affected the deposition of some microelement within the station point of the some location, this development were expressed in some trend from the figures, such conditions implies that the velocity of flow experienced variations thus heterogeneity in the Rivers, the reflection of the velocity of flows also affected by the deposition of microelement, because accumulation on the microelements also reflected on its deposition of the River, it also shows that the concentration development of the E.coli transport process in the study environment, the oxygen deficit were also monitored, in it reflected impact on the growth rate E.coli in the River, the fluctuation of the oxygen deficit reduce the growth rates, thus the concentration of the contaminant. The results from the trend are based on the facts that E.coli grows in anaerobic environment but the their growth rates cannot be compared to that of aerobic environment, therefore the trend experience reduction in growth rate in some location and predictive values are based on these factors, the trend fluctuating in some of the figures are based on the stated conditions. The predictive values were compared with experimental values, and higher percentage developed best fits correlation.

CONCLUSION

The study has explained the observed evaluation impacts on the oxygen deficit and River Velocity on E.coli deposition in River, these two parameters were critically monitored to determined their heterogeneity in deposition, thus reflecting on the transport process of the contaminant, several experts has discussed the behaviour of these microbes in terms of growth rate in soil and water environments, but the reflection of some influential parameters such oxygen deficit and River flow velocity has not been evaluated on their various impacts. the study examined the deposition of the microbes from biological waste discharge at constant rate from human settlements, the rate of discharged were monitored to correlated the rate of oxygen deficit in the River, thus determine the effects of aquatic life in the marine environment, the growth rates of E.coli is in two ways, it is observed to growth in an aerobic and anaerobic environment, therefore the study monitored the aerobic condition in surface water and observed that it has faster growth thus decrease in the growth in anaerobic conditions, the fluctuation of oxygen deficit in initial point of discharge determined the rates of vacillation in their rates of concentrations, This is because E. coli is a facultative aerobe, the states of it facultative determined their rate of influence in variation of concentration at a given distance. The predictive were subjected to validation, and both parameters developed some high percentage of best fits correlation.

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