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A MATHEMATICAL ANALYSIS OF BREWERY EFFLUENT DISTRIBUTION IN IKPOBA RIVER IN BENIN CITY, NIGERIA

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ABSTRACT

A fundamental study was carried out in a lotic ecosystem loaded with brewery effluent and other oxygen-demanding wastes from non-point sources to ascertain the pollutant level and its potential hazardousness to aquatic live and human health in the environment studied. Samples of wastewater and river water which were taken at predetermined points, on different days, in the neighbourhood of the point source, were subjected to laboratory chemical analysis to determine the concentration of effluent parameters namely: BOD, COD, DO, and pH. Differential calculus and statistical models adapted for the analysis proved to be successful in predicting the contaminant distribution in the river thereby making the research result relevant for surface water pollution control.

Keywords: brewery effluent, septic zone, oxygen-sag-curve, point source.

INTRODUCTION

Water pollution occurs when some substance or condition so degrades the quality of a body of water that the water fails to meet quality standards and such polluted water is capable of posing harmful effect on individual organisms, population, biological communities and ecosystem.

The major problem associated with waste-loading into rivers is to determine the degree of treatment to be administered on waste water to lessen the size of a concomitant zone of oxygen-sag-curve and also assure that pollution level does not exceed the maximum contaminant level (MCL).

The discharge of wastewater and effluent into surface water bodies and the resultant deterring change in water ecology have been reported by several researchers for example, Ongley (1994), Brookes (2002), Alao *et al*., (2010), Ademoroti (1996), Manivasakam (1996). Hart (Jr), Fuller (1974) and Ekhaise and Anyasi (2005).

Moreover, Swayne *et al*., (1980) observed that poorly organized and unregulated disposal of industrial and domestic wastes are regarded as major causes of deterioration of aquatic environment. Odiete (1999) states that changes brought about by pollution in water bodies may create hazards both to human and animal health and may render water unfit for domestic, industrial and agricultural activities and otherwise.

In his study conducted on brewery effluent on Ikpoba River, Eguaoje (1993) observed as follows:

i. The natural quality of Ikpoba River has been considerably affected by the effluent discharge into it by operating alcoholic beverage companies in the vicinity of the river.
ii. The pollutive effluent is highly oxygen demanding; has a high level of suspended matter, highly coloured, choking in odour and discharged in high quantities. The study further noted that the total microbal density and aquatic life have been adversely affected.

Oguzie and Okhagbuzo (2010), Ekhaise and Anyasi (2005) carried out studies of brewery effluent discharged in the same Ikpoba river and observe that aquatic life in that system is threatened because the level of pollution is alarmingly high. Whereas the former employed statistics to analyze empirical data collected, the latter used mere data presentation to examine the problem.

The works of Eguaoje, Oguzie and Okhagbuzo, Ekhaise and Anyasi are seminal and the present study intends to develop on them. The main purpose of this study is to assess the level of hazardousness and the extent of distribution of the effluent in the river.

Ikpoba river is a fourth order (4^{o}) stream flowing from north to south through Benin City, (Lat 6.5^{o} N long 5.8^{o}E). Ikpoba River rises from Ishan plateau in the east coastal plain to north east of Benin City, at an elevation of about 230m above sea level (Benka-Coker and Ojior, 1995). The river runs along an incised valley, a sandy rolling terrain, which constitutes a part of Nigerian coastal plain. The Ikpoba River runs north to south, traversing the city before crossing the Benin-Agbor road, after which it turns in a south east direction to Josun and Ossiomu River which eventually discharges into Benin River. In the initial reaches of Ikpoba River, it is completely shaded by dense vegetation of tropical forest. The river is at its middle age. As the river proceeds downstream, the vegetation clears gradually and eventually the river receives adequate amount of sunlight throughout its width. Most of the activities around the upper reaches of the river are agricultural, farming and fishing. However, it receives effluent from breweries, University of Benin Teaching Hospital (UBTH) via their drainage system and Oredo Local Government owned abattoir, which is situated along the bank of the river. Two breweries discharge their effluent into Ikpoba River.

From the description given above, it is evident that this river is used by the inhabitants around there for domestic and agricultural purposes. Therefore discharge of untreated effluent into the river May likely cause

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epidemics. The result of this study would be helpful in finding long term solution to the river pollution problem.

METHODOLOGY

Samples of effluent were collected daily over a period of ten (10) days, at 1 meter interval from the point of discharge (P) into the river, up to 10 meters downstream as shown in Figure-1. These samples were analyzed for COD, BOD, pH and DO concentration in a chemical laboratory. In addition, we took measurements of the width and depth of the river at several points in order to obtain average values. The diameter of the pipe through which the effluent flows into the river was measured also. The speed of the river was determined by allowing a piece of floating cork to transverse through a known distance and the time taken to cover the distance was observed.

Data collections at 1m interval over 10m span for 10 days were conducted in order to ascertain if there are variations in effluent concentration along the river over time.

Our main research tools are ANOVA schemes, first and second order differential equation and factorial experimental design. A 2-litre capacity measuring cylinders were used to collect samples in the river. The following procedures were adopted in the analysis of effluent parameters.

Water and sediment analysis

An HACH pH meter was used for pH determination. Determination of Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), and Chemical Oxygen Demand (COD), were carried out according to standard methods for the examination of water and wastewater as described in William (1984), ASTM (1989) and Ademoroti (1996).

Model Building

(i) With Partial Differential Equation (PDE)

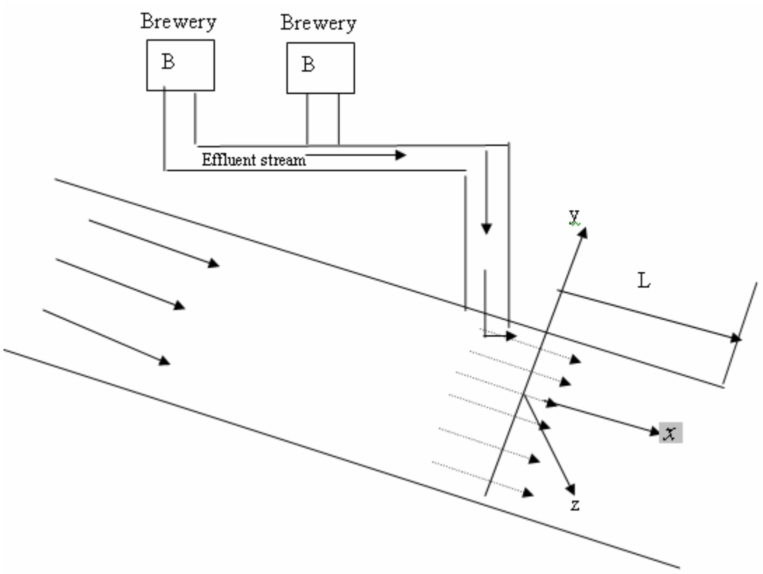

Figure-1a. Sketch of effluent stream discharge into Ikpoba River.

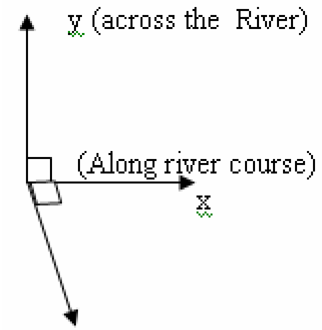

Figure-1b.

y = is measured along the width of the river
x = is measured along the length L, of the river
z = measures the depth of the river
Q = discharge rate g/sec.
C = Concentration in mg/L or ppm
U = river speed in metres/sec
A = cross sectional area of river in m^2

C = C (x) only, it varies along down stream only but not across river bank or down the river bed. C (x) twice differentiable in x. In other words, $c''(x) = \frac{dc^2}{dx^2}$ exists.

β = 0.0447g/s/g (the values for the chemical decay constant can be obtained from the literature, these values are peculiar to the type of chemical plant in question, from literature β = 0.0447g/s/g for waste water effluent associated with brewery industries)

0< x < L (Figure-1a).

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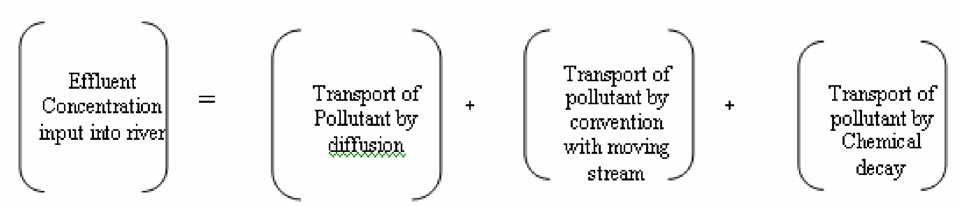
Conducting a mass balance, we notice that:



$\frac{-Q(X)}{A}$ $\quad kC''$ $\quad -UC'$ $\quad -\beta C$

$$\therefore -\frac{Q(x)}{A} = kC'' - UC' - \beta C \qquad (1)$$

$$\Rightarrow kC'' - UC' - \beta C = -\frac{Q(x)}{A}, \qquad -\infty < x < \infty \equiv UC' + \beta C = \frac{Q(x)}{A} \qquad (2)$$

$$kC'' = k\nabla^2 C = k\frac{\partial^2 c}{\partial x^2}$$

$$UC' = U\nabla C = U\frac{\partial c}{\partial x}$$

Thus we see that the diffusion of a chemical pollutant in a river is governed by the partial differential equation (PDE) of mathematical physics.

If we ignore the diffusion component of (1), we shall have

$$UC' + \beta C = \frac{Q(x)}{A} \qquad (3)$$

And the general solution of (2) is:

$$C(x) = \frac{Q(x)}{A\beta}\left(1 - e^{-\beta}/_{\mu}\right) + C_0 e^{-\mu x/\mu} \qquad (4)$$

However, if this term is not ignored, then the general solution becomes

$$C(x) = (A + Bx)e^{-0.11175x} \qquad (5)$$

This is an exponentially damped or special case of Fourier series.

(ii) ANOVA model

ANOVA test was carried out for each of the effluent parameters namely: BOD, COD, DO AND pH in that order. One metre step distance over 10m constitutes treatments while each of the ten days the samples were taken constitutes the block according to the two factor ANOVA cross-design with fixed effects procedure.

Experiment design

Model

$$X_{ijk} = \mu + \alpha_j + \beta_i + (\alpha\beta)_{ij} + \varepsilon_{ijk} \qquad (6)$$

Hypothesis:

(i) $H_o : All\ \alpha_j = 0,\ \forall j$; H_o : all $\beta_i = 0$, $\forall\ i$, and all $(\alpha\beta)_{ij} = 0$

(ii) $H_1 : some\ \alpha_j \neq 0; some \beta_i \neq 0\ and\ some\ (\alpha\beta)_{ij} \neq 0$

Reject H_o if the F-ratio of the effect being tested exceeds the tabular (critical) value, Duncan multiple range tests is evoked if treatment effect is rejected. In the Duncan multiple range test, the treatments, n in number, are averaged and the values arranged in ascending order. The standard error of the set of average values is computed from:

$$S_{y_i} = \sqrt{\frac{MSE}{n}} \qquad (7)$$

Next, the Duncan's Table of significant ranges is consulted to obtain.

$r_\alpha(p_1 f)$, *for* p= 2, 3,..., n

Where α = significance level, and
f = degree of freedom
Finally, we obtain

$$R_p = r_\alpha(p_1 f)S_{yi},\ for\ p = 2, 3, ..., n$$

Then $n(n-1)/2$ pairs are obtained and compared with the corresponding least significant ranges. On the basis of this comparison, we can see, at a glance, if significant differences exist among the pairs or means compared.

(iii) Latin square model

In this version the effluent parameters: BOD, COD, DO AND pH were randomized in the cells of 4x4 matrix and blocks of days. Two meters steps for treatments and two days steps were considered for treatment and blocks respectively. This is a special case of a 3-factor cross design given by:

$$X_{ijk} = \mu + \alpha_j + \beta_i + (\alpha\beta)_{ij} + \gamma_k + \varepsilon_{ijk}, \quad (\alpha\beta)_{ij} = 0 \qquad (8)$$

Hypothesis

Set A = BOD, B = COD, C = DO and D = pH as treatment codes.

Then $H_o : \mu_A = \mu_B = \mu_C = \mu_D$

H_1: at least two of the above means are not equal

Reject H_0 if

$$F_{calculated} > F_{(p-1),(p-2)(p-1)}$$

p = no of effluent parameters
Since p = 4

$$F_{cal.>F_{3,6,0.05}} = 4.76$$

RESULTS

The COD observations, which relates to chemical decay constant β in g/sec/g, were substituted in the ODE solution.

$$C(x) = \frac{Q(x)}{A\beta}(1 - e^{-\beta x/v}) + C_0 e^{-\beta x/v} \quad (9)$$

The governing boundary conditions were used to evaluate the ODE parameter and the results are as follows:
A = 256.5m^2
β = 0.447g/sec/g, C_0 at 1m is the various daily COD.
$Q(x)_{x=0}$ = 32637g/s/m

The C_0 represents the COD readings, x the distances in meter, Q, the discharge rate; A, the cross sectional area of the river; C (x), the distribution of concentration of effluent in the river.

$$C(x) = 2.85 \times 10^3[1 - e^{0.056x}] + 2.71 \times i0^3 e^{0.056x} \quad (10)$$

which is distance dependent.

The distribution of concentration COD at 1 metre apart for 10 meters down stream is presented in Table-1.

Table-1. Distribution of effluent concentration by first order differential equation C (x) mg/l.

DAY	1m	2m	3m	4m	5m	6m	7m	8m	9m	10m
1	2859	2708	2565	2430	2302	2181	2066	1950	1855	1758
2	2963	2807	2658	2532	2385	2259	2140	2028	1921	1821
3	2888	2735	2590	2454	2324	2202	2089	1969	1873	1775
4	2727	2583	2446	2303	2182	2068	1959	1849	1759	1667
5	2982	2824	2675	2534	2400	2273	2154	2037	1933	1832
6	2613	2476	2345	2226	2105	1890	1784	1697	1697	1609
7	2329	2207	2092	1982	1878	1780	1687	1592	1615	1437
8	2566	2431	2303	2182	2178	1959	1856	1752	1667	1580
9	2424	2297	2176	2062	1954	1852	1755	1656	1577	1495
10	2803	2654	2514	2382	2256	2138	2025	1912	1818	1723

For the 2nd order differential equation, the solution is:

$$C(x) = (A + Bx)e^{-0.11175x} \quad (11)$$

Table-2 below shows the diluted and undiluted sample values

Second order differential equation

C (x) is governed by the differential equation

$$kC'' + UC' + \beta C = \frac{Q(x)}{A} \quad (12)$$

; $(-\infty \le x \le \infty)$

Q (x) is the constant Q over the internal $0 \le x \le L$ zero outside that interval.

$\therefore$ in the interval of consideration above

$$\text{i.e. } -\infty \le x \le \infty, Q(x) = 0$$
$$kC'' + UC' + \beta C = 0 \quad (13)$$

; with $\frac{Q(x)}{A} \to 0$

Equation (1) is a 2nd order homogeneous linear differential equation with constant coefficients. It can be shown by dimensional analysis that:

$$k = \frac{U^2}{4\beta} \quad (14)$$

COD Test

Table-2. COD test for diluted sample river water.

DILUTED SAMPLE											
Sample	**1m**	**2m**	**3m**	**4m**	**5m**	**6m**	**7m**	**8m**	**9m**	**10m**	**NESTREA** (mg/l) **80**
1	2860	2843	2809	2758	2690	2606	2506	2390	2256	2106	
2	2970	2956	2929	2887	2832	2763	2680	2583	2473	2348	
3	2890	2873	2830	2770	2708	2566	2403	2250	2219	2199	
4	2720	2705	2675	2631	2556	2469	2367	2265	2245	2152	
5	2990	2971	2933	2875	2760	2626	2473	2300	2281	2243	
6	2600	2587	2561	2521	2469	2403	2325	2233	2128	2010	
7	2300	2290	2272	2245	2210	2165	2023	1978	1898	1810	
8	2550	2534	2501	2452	2368	2321	2239	2157	2042	1895	
9	2400	2385	2366	2333	2287	2231	2164	2085	1995	1894	
10	2800	2784	2752	2705	2643	2565	2500	2428	2372	2300	

$$\left(\frac{m^2}{S}\right)=\frac{\left(\frac{m}{s}\right)^2}{g/s/g}$$

$$\left(\frac{m^2}{s}\right)=\left(\frac{m^2}{s}\right) i.e.\ b^2=4ac,\ U^2=4k\beta$$

The value of k thus obtained from equation (11). can be compared with the standard form of a 2nd - order homogeneous-linear differential equation with constant coefficient:

$$a\frac{d^2y}{dx^2}+b\frac{dy}{dx}+cy=0,\ \text{y}=f(x)$$

$$\therefore k=a, \mu=b, \beta=c$$

There are two solutions for equation (1). The auxiliary equation for equation (1) in given as

$$kM^2+UM+\beta=0$$

$$M=\frac{-U\pm\sqrt{U^2-4k\beta}}{2k}$$

$$M=\frac{-U\pm\sqrt{D}}{2k}$$

Where $D=U^2-4k\beta$ is called the discriminant for D=0

$$M=\frac{-U\pm 0}{2k}=\frac{-U}{2k}$$

From equation (2) $k=\frac{U^2}{4\beta}$

$$\frac{(0.8)^2}{4(0.0447)}=3.58m^2/s$$

$$\therefore M=\frac{-0.8}{2(3.58)}=-0.11175(twice)$$

$$C(x)=(A+Bx)e^{Mx}$$

is the general solution to 2nd - order homogenous differential equation whose auxiliary equation has two equal roots.

$$\therefore C(x)=(A+Bx)e^{-0.11175x} \quad (15)$$

A, B are constants to be determined

Boundary conditions

C (0) =3000

$C'(x)=\frac{dC}{dx}=0$ (Because the concentration has not changed at the point of discharge)
From equation (3),

$C'(x) = (A + Bx)(-0.11175e^{-0.11175x}) + e^{-0.11175x}(B)$

$C'(X) = e^{-0.11175x}[B - 0.11175(A + Bx)]$

for C(0)=3000, equation (10) becomes,

$3000 = [A + B(0)]e^0$

$3000(A)e^0 = A$

i.e. $A = 3000$

$3000 = [A + B(0)]e^0$

for $C'(0) = 0,$ equation (12) becomes

$0 = e^{-0.11175(0)}[B - 0.11175(A + B(0))]$

$0 = e^0(B - 0.11175A)$

$0 = B - 0.11175A$

$B = 0.11175A$

$B = 0.11175(3000) = 335.25$

$$C(x) = (3000 + 335.25x)e^{-0.11175x} \quad (16)$$

for B, $C'(x) = \frac{dc}{dx} = 0$ because the concentration has not changed at point of discharge.

The distribution of effluent concentration can be represented by signals that resemble Fourier series. It is damped by the decay exponential function $e^{-0.11175X}$ hence the signal, i.e., concentration dies off (tails off) down stream as $x \to \infty$

However, without much loss of engineering accuracy, the function, as tabulated in Table-4 can be represented by a simple function within the zone of pollution $0 < x < L$, where L is a few breadths measured downstream. Then the Fourier signal can be approximated by

$Y = ax^2 + bx + c$

$C(x) = -5.42x^2 - 42.34x + 3023.85$

Where, a = -5.42, b = -42.34, c = 3023.85,

This was obtained with the aid of a programmable calculator.

Table-3. Distribution of Concentration by 2nd Order Differential Equation.

x (m)	0m	1m	2m	3m	4m	5m	6m	7m	8m	9m	10m
C(x)mg/L	3000	2983	2935	2865	2776	2675	2563	2446	2324	2201	2078

Table-4. ANOVA results.

DO					BOD				
Source of variability	**Df**	**SS**	**MS**	**F-Ratio**	**Source of variability**	**Df**	**SS**	**MS**	**F-Ratio**
SS column treatment	9	20.05829	2.228699	18.66	SS column treatment	9	1190406.7	132267.41	344
SS row	9	3.766301	0.4184778	3.50	SS row	9	419186.69	46576.298	121
SS error	81	9.676318	0.1194607		SS error	81	31170.41	384.819	
Total	99	33.50091			Total	99	164076379		
COD					**pH**				
Source of variability	**Df**	**SS**	**MS**	**F-Ratio**	**Source of variability**	**Df**	**SS**	**MS**	**F-Ratio**
SS column treatment	9	4411586	490176.2	182	SS column treatment	9	94.25691	10.47299	264.89
SS row	9	3633066	403674	149.7	SS row	9	49.42969	5.49218778	137.1
SS error	81	218404	2696.35		SS error	81	3.2025	0.039537057	
Total	99	8263056			Total	99	146.8891		

COD

$F_{calculated} = (182) > F_{9, 81.05} = 1.96$

We do not have sufficient evidence to accept H_0: $\alpha_j = 0$; $\beta_j = 0$

BOD

$F_{calculated} = (344) > F_{9, 81.05} = 1.96$

We do not have sufficient evidence to accept H_0: $\alpha_j = 0$; $\beta_j = 0$

DO

$F_{calculated} = (18.66) > F$

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Our experimental data do not provide enough evidence for us to accept the null hypothesis, H_o:

Ho: αj = 0; βj = 0

pH
$F_{calculated} = (264.891) > F_{9, 81.05} = 1.96$

We do not have sufficient reason to accept the null hypothesis, H_0: $\alpha_j = 0$; $\beta_j = 0$

BOD

Table-4 above confirms that the F-ratios for treatment and block effects far exceed the critical values and thus leading us to conclude that both block and treatment components of variance exist. The import is that BOD changes downstream and with time. The Duncan multiple range tests for this variability is sketched below.

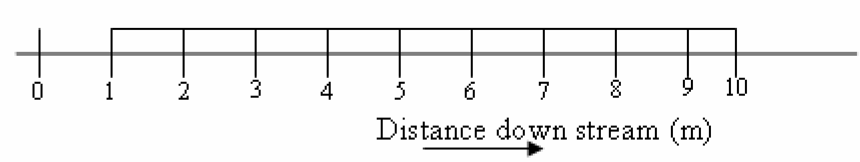

Figure-2. Duncan multiple range for test BOD changes.

The tests confirm that significant differences exist between the 24 pairs of points considered except for adjacent points. This suggests that BOD concentration gradient is rather moderate downstream. The implication of this distribution is that, perhaps several river breadth distances down stream of the river, from the point of discharge of the effluent, resulting population explosion of decomposer organisms uses up so much of the dissolved oxygen supply that most fish and other forms of aquatic life cannot survive.

COD

The computation under COD column presents preponderance of evidence that prompts us to reject the null hypothesis that COD distribution down stream of the river is the same, Duncan multiple range test conducted confirm that COD levels drop sharply down stream. In other words, the amount of dissolved oxygen is very high at the zone of pollution implying that DO-deficiency level is remarkable at this area.

DO

As with the other previous two effluent parameters, DO demand varies with time and distance. However, the Duncan multiple range test suggest that there is no perceptible difference in DO concentration with distance about 1 meter apart. However, significant differences exist at two points more than 1 meter apart.

pH

As in the other cases, rejecting the null hypothesis means that there is variation in pH concentration down stream. Duncan multiple range test confirms that significant differences exist in the values of pH measured at adjacent points 1m or more apart.

In particular, we note that Duncan multiple range confirm that the all effluent parameters namely BOD, DO, COD and pH are time and distance dependent.

Latin square analysis result

Table-5. Below tabulates the ANOVA of the Latin Square version of the analysis.

Source of variability	DF	SS	MS	F-RATIO
Treatment	3	18398997.6	6132999.2	308.2088
SS row	3	80739.21	26913.07	
Columns	3	121312.6075	40437.53	
SS error	6	119393.0636	19898.84393	
Total	15	1872044.28		

$F_{calculated} = (308.2088) > F_{3, 6, 0, 5} = 4.76$. Reject H_0: $\alpha_j = 0$; $\beta_j = 0$

Source of variability	DF	SS	MS	F-RATIO
Treatment	3	16945814.38	5648604.793	190.58
SS Row	3	122630.28	40876.76	
Columns	3	167901.87	55967.29	
SS Error	6	177831.43	29638.57167	
Total	15	17414177.9		

$F_{calculated} = (190.58) > F_{3, 6, 0.5} = 4.76$. Reject H_0: $\alpha_j = 0$; $\beta_j = 0$

The results of the table incline us to conclude that treatment means are different, that is, the effluent parameters' concentrations vary downstream. The Duncan multiple range test is sketched below.

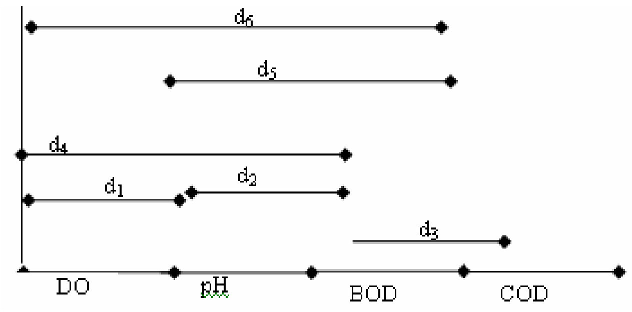

Figure-3. Duncan test DO results for pH for the effluent parameters.

All d_i's (i= 1, 2… 4) are significant except d_1. This implies that there is no significance difference between dissolved oxygen and pH concentrations but there are significant differences between any pairs of effluent parameters over time and distance.

DISCUSSIONS

In the course of the analysis it was apparent that Ikpoba River is continually over loaded with untreated discharge from brewery waste to the effect that a considerable extent of septic zone of oxygen sag curve incapable of sustaining aquatic communities has been established. Besides the brewery point sources, non point sources from erosion water, hospital wastes, feed lots/abattoirs, non traceable spills of used engine oils from municipal waste-water conduits also contribute to the observed pollution in the river.

The results of an earlier studies on the same river conducted by Eguaje (1993), Ekhaise, and Anyasi (2005), and Oguzie and Okhagbuzo (2010) suggest that pollutant concentration in the river is significantly high and, as a matter of fact, far exceeds the maximum contaminant level (MCL) specified by National Environmental Standard and Regulation Enforcement Agency (NESREA), which is the Agency which has the responsibility to enforce compliance with environmental standards, rules, laws, policies and guidelines in Nigeria.

The current unchecked environmental practice had obvious implications to human health and safety of aquatic live in the ecosystem. Our research results point to imminent threat of water-borne infectious diseases such as typhoid, hepatitis, cholera and dysentery. There is also seeming potential hazardousness to livestock such as: herd of cattle, flock of sheep, tribe of goats, etc.

The models employed in the analysis have also helped to clarify thinking on the level of pollution on the river as well as its likely consequences. Perhaps the most spectacular result of this study is that the distribution of pollutant discharge into river follows an exponentially damped sinusoidal signal that tails off to insignificance several river-width distances downsteam due to infinite dilution. It is a natural regeneration cycle if the pollution process is not repeated downstream, which is often rarely the case.

CONCLUSIONS

The foregoing analysis and discussion lead to the following informative conclusive statements:

- There is considerable loading of brewery effluent within the segment of Ikpoba River studied; and
- The effluent parameters obtained indicate that, in the vicinity of the point sources, a septic zone of low dissolve oxygen caused by the presence of oxygen consuming waste had developed. This condition is hazardous to aquatic life, human population and livestock. To the aquatic communities. It is capable of causing asphyxiation within the septic zone. To the human population and livestock there appears to be imminent threat of waterborne diseases specified above.

RECOMMENDATIONS

Whether or not our conclusions will stand up to scrutiny, it is nevertheless important to consider the caveats raised in this paper. Further work can be undertaken to improve the usefulness of the findings of the study.

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