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Predicting the Impact of a Food Processing Industry on Water Quality of its Environment

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Abstract: A 2^4 full factorial design was used to predict the impact of NAS Foods Nigeria Limited on the water quality of its environment. The factorial, main and interaction effects of four water pollutants, namely, Total Dissolved Solids (TDS), sulphide of lead (PbS), Total Nitrates (TNL) and Total Undissolved Solids (TUS) on Biological Oxygen Demand (BOD) were obtained statistically. From the sensitive analysis, it was concluded that all the main effects and interactions in the model have significant impacts on the level of BOD of the surface water. However, TDS, TNL and TUS have higher detrimental influences. On the other hand, the interactions TDS/PbS/TUS, TDS/PbS and PbS/TUS all have high incremental influences on Dissolved Oxygen (DO). The statistical analysis of the experimental data showed that the developed model is adequate for obtaining optimum conditions of 2000 mg L^{-1} for TDS, 0.2 mg L^{-1} for PbS, 10 mg L^{-1} for TNL and 2030 mg L^{-1} for TUS. Validation of the model gave a correlation coefficient of 0.999251 between the measured and predicted values.

Key words: Biological oxygen demand, environment, factorial design, food processing, impact prediction, water quality

INTRODUCTION

Food processing projects involve the processing and packaging of meat products, fish and shell fish, dairy products, fruits and vegetables, grains and beverages production. It includes refinement, preservation and improvement of product; storage, handling, packaging and canning. The industry generates large volumes of wastewater, solid and gaseous wastes which may also be a source of water pollution (Chukwu, 2005). Pollution of water occurs when too much of an undesirable or harmful substance flows into a body of water, exceeding the natural ability of that water body to remove the undesirable material or convert it to a harmless form. The degree of water pollution is expressed in mg L^{-1} of water pollutants. Solid and liquid wastes are usually analyzed for such water quality parameters as Total Dissolved Solids (TDS), Total Undissolved Solids (TUS), sulphide of Lead (PbS), Total Nitrates (TNL), Biological Oxygen Demand (BOD) and Dissolved Oxygen (DO).

Biological Oxygen Demand (BOD) is a critical and commonly used measure in surface water quality management (FEPA, 1995). It is the amount of oxygen required for biological decomposition of dead organic matter. There is an inverse relationship between BOD and DO. It has been established that there is a relationship between BOD, TDS, PbS, TNL and TUS (Chukwu, 2005). TDS, TNL and TUS (organics) all lead to eutrophication (or nutrient enrichment). In a water body low in nutrients, there are little algae, the water is relatively clear and there is enough dissolved oxygen for the fish and other aquatic lives. When an organic waste is added to the water, it enters the water and stimulates the growth of algae. The algae become so abundant that a dense layer is formed which cuts off the sunlight and kills the algae on the bottom. The algae are fed upon by bacteria, who use up the oxygen in the water (i.e., high BOD) and the fish and other aquatic lives die from lack of oxygen (i.e., low DO) (Kupchella and Hyland, 1993; Chukwu, 2005).

Lead sulphide (PbS) is linked with BOD in a different way. Some chemical elements are directly toxic to organisms. When lead is carried by streams and rivers, deposited in non-flowing waters, or transported to the oceans or lakes, it is taken up by aquatic organisms. In concentrations higher than the permissible limits, the organisms die. If the dead organisms are those involved in organic matter decomposition it leads to low BOD. This ultimately gives rise to increased DO, leading to the multiplication of aerobic organisms, which finally deplete the water of its oxygen (Chukwu, 2005). It has been shown that:

$$BOD = f(TDS, TNT, TUS, PbS) \qquad (1)$$

The main reason for this research is to forestall some of the problems associated with industrial development. Therefore, there is need to subject the industrial site to an impact evaluation to predict the likelihood of adverse effects on the environment. Predicting, the impact of an industry on the water quality of its environment was therefore, targeted towards controlling wastes, pollution and epidemic-related industrial activities. Prediction is used to estimate the changes in an environmental parameter (e.g., water quality) and the subsequent effects (e.g., increased BOD). Prediction may employ mathematical, physical, socio-cultural and economic models or experiments and expert judgements in quantifying impacts (Christensen *et al.*, 1990). Since, prediction of impact involves uncertainty in terms of probabilities or margins of error, a sensitivity analysis is usually an integral part of a prediction study. In this study, a mathematical model was used for the impact prediction. In general, the output variable (M) is a function of one or more input variables

$$(A, B, C \ldots): M = f(A, B, B, \ldots) \qquad (2)$$

MATERIALS AND METHODS

Description of the study area: The industrial environment modelled in this study is that of NAS Foods Nigeria Limited. The industry is located at No.44 Yakubu Gowon Way, Jos, Plateau State. Jos is on Lat. 9°52'N and Long. 8°54'E. It is about 1250 m above sea level on the Delimi River. The average monthly temperatures range between 21 and 25°C. The monthly rainfall ranges from 200-325 mm between May and September and 2.5-85 mm for the months of January through April and October through December (Roder, 2004).

Determination of the water quality parameter: It has been established in Eq. (1) that there is a relationship between BOD and TDS, PbS, TNL and TUS. To determine the BOD of the stream into which the solid and liquid wastes from NAS foods industry were discharged, 3 points along the stream were chosen at 50, 100 and 150 m away from the point of discharge. Water samples were taken from these points and labelled as blanks. The effluent was discharged and after 30 min, samples of water were taken at the 3 observation points of 50, 100 and 150 m. The blanks and treated samples were preserved for laboratory analysis. The measurement was done each day there was a processing operation and the monthly averages for BOD were used for model development. Spent lubricant was analyzed for lead as lead sulphide before being discharged. The leachate from land fill site and the effluent were analyzed for total nitrates and TDS before they entered the receiving stream. The solid waste was analyzed for dry matter. For all the analyses the AOAC (1980) nutritional guidelines were followed.

The experimental design: The design table (or calculation matrix) for the 2^4 full factorial experiments is shown in Table 1 (Montgomery, 1991). It indicates the mode of conducting the experiments. With 4 variables and 2 levels, a complete design leads to a total of 16 runs or observations. In the 2^4, full factorial experiments, the low and high levels of the factors were coded as '-' and '+', respectively. The levels of the 4 factors are listed in standard order in the columns X_1, X_2, X_3 and X_4 in the Table 1. The sequence of + and - signs in the columns indicates how to combine the observations to get the main effects and the interactions. Columns X_1, X_2, X_3 and X_4 are the main effects, while columns X_{12} through X_{1234} are the interactions. The generalized regression equation of the model is given in Eq. (3).

$$\begin{aligned} Y = {} & b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{12}X_{12} + b_{13}X_{13} \\ & + b_{14}X_{14} + b_{23}X_{23} + b_{24}X_{24} + b_{34}X_{34} + b_{123}X_{123} \\ & + b_{124}X_{124} + b_{134}X_{134} + b_{234}X_{234} + b_{1234}X_{1234} + e_i \end{aligned} \qquad (3)$$

Table 1: Design matrix for a 2^4 Full Factorial Experiment (FFE)

X_0 b_0	X_1 b_1	X_2 b_2	X_3 b_3	X_4 b_4	X_{12} b_{12}	X_{13} b_{13}	X_{14} b_{14}	X_{23} b_{23}	X_{24} b_{24}	X_{34} b_{34}	X_{123} b_{123}	X_{124} b_{124}	X_{134} b_{134}	X_{234} b_{234}	X_{1234} b_{1234}
+	-	-	-	-	+	+	+	+	+	+	-	-	-	-	+
+	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-
+	-	+	-	-	-	+	+	-	-	+	+	+	-	+	-
+	+	+	-	-	+	-	-	-	-	+	-	-	+	+	+
+	-	-	+	-	+	-	+	-	+	-	+	-	+	+	-
+	+	-	+	-	-	+	-	-	+	-	-	+	-	+	+
+	-	+	+	-	-	-	+	+	-	-	-	+	+	-	+
+	+	+	+	-	+	+	-	+	-	-	+	-	-	-	-
+	-	-	-	+	+	+	-	+	-	-	-	+	+	+	-
+	+	-	-	+	-	-	+	+	-	-	+	-	-	+	+
+	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+
+	+	+	-	+	+	-	+	-	+	-	-	+	-	-	-
+	-	-	+	+	+	-	-	-	-	+	+	+	-	-	+
+	+	-	+	+	-	+	+	-	-	+	-	-	+	-	-
+	-	+	+	+	-	-	-	+	+	+	-	-	-	+	-
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

where:

Y = Environmental element being predicted.
b's = Regression coefficients of the model.
X's = Coded variables.
e_i = Random error with 0 mean and constant variance.

Mean, $$\bar{Y}_u = \frac{1}{r}\sum_{v=1}^{r} y_{uv} \quad (4)$$

Dispersion, $$S_u^2 \frac{1}{r-1}\sum_{v=1}^{r}\left(Y_{uv} - \bar{Y}_u\right)^2 \quad (5)$$

$$\text{Sum of the dispersions} = \sum_{u=1}^{N} S^2_{uv} \quad (6)$$

$$\text{Maximum dispersion} = S_u^2 \max \quad (7)$$

The G-test (Cochran G-criteria) is used to ascertain the possibility of carrying out regression analysis. The calculated G-value is given as:

$$G_{cal} = \frac{S_u^2 \max}{\sum_{u=1}^{N} S_u^2} \quad (8)$$

The calculated G-value is compared with the appropriate table value. The condition that must be satisfied before regression analysis can be carried out is:

$$G_{cal} < G_{[\alpha, N(r-1)]} \quad (9)$$

The dispersion (mean-squared-error) and the experimental error are given by Eq. (10) and (11), respectively.

$$S_y^2 = \frac{1}{N}\sum_{u=1}^{N} S^2_u \quad (10)$$

$$S_y = \sqrt{S_y^2} \quad (11)$$

The adequacy of the regression model was evaluated by carrying out a test of hypothesis using ANOVA on the individual regression coefficients. The sums of squares for the effects were calculated using Eq. (12) through (15). The total sum of squares was found using Eq. (16). The error sum of squares was calculated using Eq. (17 or 18) and the F-ratios were calculated using Eq. (19).

For the main effects:

$$SS_{bi} = \frac{r}{N}\sum_{u=1}^{N}\left(X_i \bar{Y}_u\right)^2 \quad (12)$$

For the two-factor interactions:

$$SS_{bij} = \frac{r}{N}\sum_{u=1}^{N}\left(X_{ij} \bar{Y}_u\right)^2 \quad (13)$$

For the three-factor interactions:

$$SS_{bijk} = \frac{r}{N}\sum_{u=1}^{N}\left(X_{ijk} \bar{Y}_u\right)^2 \quad (14)$$

For the four-factor interactions:

$$SS_{bijkl} = \frac{r}{N}\sum_{u=1}^{N}\left(X_{ijkl} \bar{Y}_u\right)^2 \quad (15)$$

The total sum of squares SS_T is given as:

$$SS_T = \sum_{u=1}^{N.r} Y_{uv}^2 - \frac{\left(\sum_{u=1}^{N.r} Y_{uv}\right)^2}{N.r} \quad (16)$$

The error sum of squares (SS_E) is given as:

$$SS_E = SS_T - \sum SS_R \quad (17)$$

Equation (17) can also be written as:

$$SS_E = SS_T - SS_{bi} + SS_{bj} + \ldots + SS_{bijkl} \quad (18)$$

The appropriate test statistic is the F-test given as:

$$F_{cal} = \frac{MS_R}{MS_E} = \frac{SS_R}{df_R} \quad (19)$$

If $F_{cal} > F_{(\alpha,\, dfR,\, N(r-1))}$, the null hypothesis is rejected. The adequacy of the regression model was further checked by calculating the dispersion of adequacy using Eq. (20) for the replicate experiment and comparing the magnitude with the variance estimate given by the mean -squared-error and by using Fisher's criteria (Eq. 21). The dispersion of adequacy for the replicate experiment is given by:

$$SS^2_{(ad)} = \frac{r}{N-\lambda}\sum_{u=1}^{N}\left(\bar{Y}_u - \hat{Y}_u\right)^2 = \frac{r}{df(ad)}\sum_{u=1}^{N}\left(\bar{Y}_u - \hat{Y}_u\right)^2 \quad (20)$$

where, λ is the number of inadequate coefficients. Fisher's criteria (F-test) are used to determine the adequacy of the regression model.

$$\frac{F_{cal}}{S_y^2} = SS^2_{(ad)} \qquad (21)$$

S_y^2 = Variance estimate given by the mean-squared-error.

RESULTS

The surface water quality data are presented in Table 2, while the surface water quality data showing dispersions are presented in Table 3.

From Table 3, S_u^2 max = 0.0533335 and from Eq. (6)

$$\sum_{u=1}^{16} S_u^2 = 0.3365685$$

From Eq. (8), G_{cal} = 0.1585 and from statistical tables $G_{tab\ (0.05,\ 2,\ 16)}$ = 0.3222. Since, $G_{cal} < G_{tab}$, regression analysis was carried out. The regression coefficients b_0, b_1, b_2, b_3, b_4, b_{12}, b_{13}, b_{14}, b_{23}, b_{24}, b_{34}, b_{123}, b_{124}, b_{134}, b_{234} and b_{1234} were calculated from information in Table 1 and 2 using Yates' Algorithm (1937) as modified by Chukwu (2005). The coefficients are 6.78, 0.54, -0.14, 0.11, 0.51, -0.62, 0.02, 0.04, -0.05, -0.44, 0.006, 0.15, -0.95, 0.10, -0.12 and 0.24, respectively. Applying Eq. (10) and (11), the dispersion (average sample variance) and the experimental error are 0.021035531 and 0.14503631, respectively. The regression model, using only the statistically significant coefficients, is:

$$\begin{aligned} B_N = {} & 6.78 + 0.54X_1 - 0.14X_2 + 0.11X_3 + 0.51X_4 - 0.62X_{12} \\ & + 0.04X_{14} - 0.05X_{23} - 0.44X_{24} + 0.15X_{123} - 0.95X_{124} \\ & + 0.10X134 - 0.12X_{234} + 0.24X_{1234} \end{aligned} \qquad (22)$$

X_1 = Total dissolved solids (TDS).
X_2 = Sulphide of lead (PbS).
X_3 = Total Nitrate Leachate (TNL).
X_4 = Total Undissolved Solids (TUS).
B_N = Biological oxygen demand (indicator of water quality).

The predicted values of BOD at the 16 points in the design were generated using Eq. (22). The mean

Table 2: Surface water quality data for NAS foods Nigeria Ltd. (September 2002 to December 2003)

Month	X_1(TDS), mg L^{-1}			X_2 (PbS)×10^{-2} mg L^{-1}			X_3 (TNL)×10^{-1} mg L^{-1}			X_4 (TUS), mg L^{-1}			BOD, mg L^{-1}			Mean
of the year	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	BOD, mgL^{-1}
Sep. 02	3.87	4.01	4.14	7.60	8.00	8.30	2.54	2.63	2.71	1.40	1.45	1.49	5.60	5.80	5.98	5.793
Oct. 02	4.29	4.22	4.15	8.60	8.30	8.30	2.81	2.76	2.72	1.54	1.52	1.50	6.20	6.10	6.00	6.100
Nov. 02	3.75	3.79	3.67	7.60	7.60	7.30	2.46	2.48	2.40	1.35	1.36	1.32	5.42	5.48	5.30	5.400
Dec. 02	5.05	5.19	5.12	10.00	10.40	10.00	3.31	3.40	3.36	1.82	1.87	1.84	7.30	7.50	7.40	7.400
Jan. 03	3.94	4.15	4.01	8.00	8.30	8.00	2.58	2.72	2.63	1.42	1.49	1.45	5.70	6.00	5.80	5.833
Feb. 03	4.22	4.19	4.43	8.30	8.30	9.00	2.76	2.74	2.90	1.52	1.51	1.60	6.10	6.05	6.41	6.187
Mar. 03	4.15	4.36	4.12	8.30	8.60	8.40	2.72	2.86	2.74	1.49	1.57	1.51	6.00	6.30	5.99	6.097
Apr. 03	4.99	5.17	5.19	10.00	10.40	10.40	3.27	3.39	3.40	1.80	1.86	1.87	7.21	7.48	7.50	7.397
May. 03	3.46	3.54	3.69	6.90	6.90	7.30	2.26	2.32	2.42	1.25	1.28	1.33	5.00	5.12	5.34	5.153
Jun. 03	8.81	8.76	8.78	5.60	5.60	5.60	1.83	1.82	1.82	1.00	1.00	1.00	10.10	10.00	10.00	10.023
Jul. 03	5.81	5.76	5.60	11.80	11.40	11.10	3.81	3.77	3.67	2.09	2.07	2.02	8.40	8.32	8.10	8.273
Aug. 03	3.46	3.73	3.73	6.90	7.60	7.60	2.27	2.45	2.45	1.25	1.35	1.35	5.00	5.40	5.40	5.267
Sep. 03	4.22	4.37	4.46	8.30	8.70	8.70	2.76	2.86	2.92	1.52	1.57	1.61	6.10	6.32	6.45	6.290
Oct. 03	8.70	8.78	8.74	12.40	13.80	13.10	1.81	1.82	1.82	0.99	1.00	1.00	10.00	10.10	10.10	10.050
Nov. 03	4.84	4.98	4.94	9.70	10.00	10.00	3.17	3.26	3.24	1.74	1.79	1.78	7.00	7.20	7.15	7.117
Dec. 03	4.29	4.27	4.25	8.60	8.60	8.70	2.81	2.80	2.78	1.54	1.54	1.53	6.20	6.18	6.14	6.173

I, II and III are replicates

Table 3: Surface water quality data for NAS foods Nigeria limited showing dispersions

Y_1	Y_2	Y_3	$\bar{Y}$	$(Y_1-\bar{Y})^2$	$(Y_2-\bar{Y})^2$	$(Y_3-\bar{Y})^2$	S^2u
5.60	5.80	5.98	5.793	0.037249	0.000049	0.034969	0.0361335
6.20	6.10	6.00	6.100	0.010000	0.000000	0.010000	0.0100000
5.42	5.48	5.30	5.400	0.000400	0.006400	0.010000	0.0084000
7.30	7.50	7.40	7.400	0.010000	0.010000	0.000000	0.0100000
5.70	6.00	5.80	5.833	0.017689	0.027889	0.001089	0.0233335
6.10	6.05	6.41	6.187	0.007569	0.018769	0.049729	0.0380335
6.00	6.30	5.99	6.097	0.009409	0.041209	0.011449	0.0310335
7.21	7.48	5.50	7.397	0.034969	0.006889	0.010609	0.0262335
5.00	5.12	5.34	5.153	0.023409	0.001089	0.034969	0.0297335
10.05	10.00	10.02	10.023	0.000729	0.000529	0.000009	0.0006335
8.40	8.32	8.10	8.273	0.016129	0.002209	0.029929	0.0241335
5.00	5.40	5.40	5.267	0.071289	0.017689	0.017689	0.0533335
6.10	6.32	6.45	6.290	0.036100	0.000900	0.025600	0.0313000
10.00	10.10	10.05	10.050	0.002500	0.002500	0.000000	0.0025000
7.00	7.20	7.15	7.117	0.013689	0.006889	0.001089	0.0108335
6.20	6.18	6.14	6.173	0.000729	0.000049	0.001089	0.0009335

Table 4: The mean experimental observations, the predicted values and the squares of the residuals for surface water quality for NAS foods Nigeria limited

$\bar{B}_N$	$\hat{B}_N$	$e^2_i = (\bar{B}_N - \hat{B}_N)^2$
5.793	5.750	0.001849
6.100	6.110	0.000100
5.400	5.370	0.000900
7.400	7.410	0.000100
5.833	5.850	0.000289
6.187	6.170	0.000289
6.097	6.110	0.000169
7.397	7.390	0.000049
5.153	5.150	0.000009
10.023	10.030	0.000049
8.273	8.250	0.000529
5.267	5.290	0.000529
6.290	6.290	0.000000
10.050	10.010	0.001600
7.117	7.150	0.001089
6.173	6.150	0.000529

Table 5: ANOVA for the replicated 2^4 factorial experiment for surface water quality for NAS foods Nigeria limited

Source of variation	Effect	Sum of squares (SS)	Degrees of freedom (df)	Mean squares (MS)	F-ratio
b_1	0.54	14.000	1	14.000	660.83
b_2	-0.14	0.990	1	0.990	47.02
b_3	0.11	0.560	1	0.560	26.64
b_4	0.51	12.420	1	12.420	586.28
b_{12}	-0.62	18.530	1	18.530	874.63
*b_{13}	0.02	0.020	1	0.020	0.79
*b_{14}	0.04	0.090	1	0.090	4.58
b_{23}	-0.05	0.130	1	0.130	6.35
b_{24}	-0.44	9.360	1	9.360	442.01
*b_{34}	0.01	0.001	1	0.001	0.08
b_{123}	0.15	1.100	1	1.100	52.05
b_{124}	-0.95	43.430	1	43.430	2049.92
b_{134}	0.10	0.480	1	0.480	22.80
b_{234}	-0.12	0.740	1	0.740	34.73
b_{1234}	0.24	2.880	1	2.880	135.93
Error		0.680	32	0.021	
Total		105.430	47		

* Insignificant at 5%

experimental observations ($\bar{B}_N$), the predicted values ($\hat{B}_N$) and the squares of the residual (e^2_i) are presented in Table 4. The ANOVA is summarized in Table 5. When each of the calculated F-ratios was compared with the appropriate critical table value $F_{(0.05, 1, 32)} = 5.54$, it was found that the coefficients b_{13}, b_{14} and b_{34} do not contribute significantly to the regression model.

Applying Eq.(20), the dispersion of adequacy for the replicate experiment is 0.0024237. Applying Eq.(21), $F_{cal} = 0.0072$ and from statistical table, $F_{(0.05, 13, 32)} = 2.03$. Since, $F_{cal} < F_{tab}$, the regression model was considered adequate. Validation of the model using the water quality data collected for the period January to December, 2004 gave a correlation coefficient of 0.999251. This shows that there is a high degree of correlation between the measured and predicted values.

DISCUSSION

To assist in the interpretation of the water quality model, a sensitivity analysis was carried out.

Factorial effects:

- Experiment 1 puts TDS (4.01 mg L^{-1}) and other factors at their low levels and the predicted value $\hat{Y}_1$ = 5.75 mg L^{-1}. Experiment 2 puts TDS (4.22 mg L^{-1}) at high level and other factors at their low levels and the predicted value $\hat{Y}_2$ = 6.11 mg L^{-1}. This means that TDS increased BOD by 0.36 mg L^{-1} or 6.3%. Actually, dissolved organic solids tend to increase BOD via the activities of decomposers. Therefore, BOD was relatively and positively sensitive to changes in TDS.
- Experiment 1 puts PbS (0.080 mg L^{-1}) and other factors at their low levels and the predicted value $\hat{Y}_1$ = 5.75 mg L^{-1}. Experiment 3 puts PbS (0.075 mg L^{-1}) at high level, while other factors are at their low levels and the predicted value $\hat{Y}_3$ = 5.37 mg L^{-1}. This means that PbS decreased BOD by 0.38 mg L^{-1} or 4.75%. Actually, Lead, even in trace quantities poisons aquatic organisms and thereby reduces the action of decomposers which tend to increase BOD. Therefore, BOD was relatively but negatively sensitive to changes in PbS.
- Experiment 1 puts TNL (0.263 mg L^{-1}) and other factors at their low levels and the predicted value $\hat{Y}_1$ = 5.75 mg L^{-1}. Experiment 5 puts TNL (0.264 mg L^{-1}) at high level, while other factors are at their low levels and the predicted value $\hat{Y}_5$ = 5.85 mg L^{-1}. This means that TNL increased BOD by 0.10 mg L^{-1} or 1.7%. From theory, leachate from organic dump sites leads to eutrophication and subsequently encourages the activities of high oxygen-demanding bacteria. Therefore, BOD was strongly and positively sensitive to changes in TNL.
- Experiment 1 puts TUS (1.45 mg L^{-1}) and other factors at their low levels and the predicted value $\hat{Y}_1$ = 5.75 mg L^{-1}. Experiment 9 puts TUS (1.29 mg L^{-1}) at high level, while other factors are at their low levels and the predicted value $\hat{Y}_9$ = 5.15 mg L^{-1}. This means that TUS decreased BOD by 0.60 mg L^{-1} or 10.4%. This contradicts the positive coefficient as indicated in the model. This could be attributed to increased sedimentation which hinders light penetration into the effluent-receiving stream. As a result, the photosynthetic activities of aquatic plants providing food for decomposers are hampered and leads to decreased population of these organisms. Therefore, BOD was relatively but negatively sensitive to changes in TUS.

Based on the sensitivity analysis, it was concluded that the BOD of the stream into which NAS discharges its effluents was strongly sensitive to TNL, relatively sensitive to TDS and relatively but negatively sensitive to PbS and TUS. Therefore, every effort should be directed towards reducing the discharge of organic wastes into the water body.

Main effects: The main effect of TDS is 0.54. This means that TDS led to 0.54 mg L^{-1} increase in BOD. This is explained by the positive sign of the coefficient of this factor (b_1= 0.54). The implication of increased BOD is decreased oxygen content of the water, hence, aquatic life is endangered. The main effect of PbS is -0.14. This means that PbS led to 0.14 mg L^{-1} decrease in BOD. This is explained by the negative sign of the coefficient of this factor (b_2 = -0.14). The main effect of TNL is 0.11. This means that TNL led to 0.11 mg L^{-1} increase in BOD. This is explained by the positive sign of the coefficient of this factor (b_3 = 0.11). The main effect of TUS is 0.51. This means that TUS led to 0.51 mg L^{-1} increase in BOD. This is explained by the positive sign of the coefficient of this factor (b_1 = 0.51).

Interaction effects: The interaction effect of TDS and PbS is -0.62. This means that increasing TDS and PbS from their low levels to their high levels decreased the BOD of the surface water by 0.62 mg L^{-1}. Each of the main effects of TDS and PbS is greater than the interaction effect, indicating that there is positive synergism between the interacting factors. The interaction effect of TDS and TUS is 0.04. This means that increasing TDS and TUS from their low levels to their high levels increased slightly the BOD of the surface water by 0.04 mg L^{-1}. However, as the interaction is very small compared to the main effect of each of the interacting factors, we say there is negative synergism between TDS and TUS. The interaction effect of PbS and TNL is -0.05. This means that increasing PbS and TNL from their low levels to their high levels decreased the BOD of the surface water by 0.05 mg L^{-1}. It also means that the presence of lead in the surface water has a masking effect on nitrates. The main effect of nitrate is 0.11, while that of lead is -0.14. The interaction is however, negatively synergistic. The interaction effect of PbS and TUS is -0.44. This means that increasing PbS and TUS from their low levels to their high levels decreased the BOD of the surface water by 0.44 mg L^{-1}. This could be due to the fact that heavy metals undergo biological concentration or biomagnifications. The interaction effect of TDS, PbS and TNL is 0.15. This means that increasing TDS, PbS and TNL from their low levels to their high levels increased the BOD of the surface water by 0.15 mg L^{-1}.

The interaction effect of TDS, PbS and TUS is -0.95. This means that increasing TDS, PbS and TUS from their low levels to their high levels decreased the BOD of surface water by 0.95 mg L^{-1}. Again there is a masking effect of lead, probably due to biomagnifications. The interaction effect of TDS, TNL and TUS is 0.10. This means that increasing TDS, TNL and TUS from their low levels to their high levels increased the BOD of the surface water by 0.10 mg L^{-1}. The interaction effect is however, small compared to the main effects of TDS and TUS but approximately, the same as the main effect of TNL. It was concluded that nitrates in water have a serious masking effect on total organic solids. The interaction effect of PbS, TNL and TUS is -0.12. This means that increasing PbS, TNL and TUS from their low levels to their high levels decreased the BOD of the surface water by 0.12 mg L^{-1}. The interaction effect of TDS, PbS, TNL and TUS is 0.24. This means that increasing the four factors from their low levels to their high levels increased the BOD of the surface water by 0.24 mg L^{-1}.

CONCLUSION AND RECOMMENDATIONS

From the sensitive analysis, it was concluded that all the main effects and interactions in the model have significant impact on the BOD of the surface water. However, TDS, TNL and TUS have higher detrimental influences. High levels of each of these led to a drastic increase in the BOD and the consequent decrease in dissolved oxygen (DO). On the other hand, the interactions TDS/PbS/TUS, TDS/PbS and PbS/TUS all have high incremental influences on DO, since, the BOD is appreciably reduced by such interactions. When the predicted values were compared with the mean experimental values (Table 4), it was observed that experiment 9, with predicted value $\hat{Y}_9$ = 5.15 mg L^{-1}, maintains the BOD of the surface water at the lowest level. Therefore, it was concluded that the optimum condition to meet the allowable BOD is that of experiment 9, that is: TDS, PbS, TNL must be at their minimum levels and TUS at its maximum level. For Nigeria, the maximum allowable level for TDS is 2000 mg L^{-1}, for PbS is 0.2 mg L^{-1}, for TNL is 10 mg L^{-1} and for TUS is 2030 mg L^{-1} (FEPA, 1991). Validation of the model showed a high degree of correlation between the measured and predicted values. This means that the model can be used to predict the effects of the food processing industry in future. It was recommended that any processing activity by the industry that could lead to the discharge of TDS, PbS, TNL and TUS into water bodies at values more than the maximum permissible limits must be discouraged.

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