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Modelling of Iron Transport in Receiving Trans-Woji Streams, Port Harcourt, Rivers State

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Abstract

This study involves the prediction of iron concentration along the upstream of stream located in Trans-Woji in Port Harcourt, Rivers State of Nigeria. Three (3) streams polluted by industrial wastes from beverage, oil drilling fluids and biscuit manufacturing industries were investigated. The concentration of iron alongside other parameters were measured, but iron content in the streams were further measured at 10 meters intervals along the streams upstream to determine the transport pattern of iron after pollution. The analysis shows industrial effluents have impact on the streams' quality. It was observed that the concentration of iron decreases with distance away from effluent disposal point, but at 50 meters away from the effluent discharged point, the concentrations of iron in the respective stream was still above the permissible limits of 0.3mg/l. However, at distance from about 200 meters away from the effluent disposal point, the model predicted very low concentration of iron even below the threshold limit. Hence, from the high prediction accuracy and the high degree of agreement between measured and predicted iron concentration, the model can be useful for prediction of heavy metals in effluent discharged into water bodies.

Key words: Iron Transport, Modelling, Stream, Effluents

INTRODUCTION

Industrial effluents are the main sources of direct and often continuous input of pollutants into aquatic ecosystems with long term implications on ecosystem functioning including changes in food availability and an extreme threat to the self regulating capacity of the biosphere. In separate studies, Sangodoyin (1995) and Ibekwe *et al*. (2004) reported an increase in industrial activities which has led to pollution of major rivers and streams in Nigeria. Also in later study, it was reported that industrial waste water entering water body represents heavy sources of environmental pollution in Nigeria Rivers (Fakayode, 2005). It affects both the water quality, microbial and aquatic flora (Ekhaise *et al*., 2005). Industrial wastes often contain organic pollutants and this is made worse by land-based sources such as occasional discharge of raw sewage through storm water outlets and industrial effluents from refineries oil terminals, petrochemical plants, brewery and food and beverages (Ajayi *et al*. 1981: Kanu *et al*. 2006). Due to population and industrial growth, land and water (river, lakes etc) becomes often the recipient of organic matter in amounts exceeding their natural purification capacity, while in the past, natural purification and dilution were usually sufficient (Osibanjo *et al*., 2011).

Water pollution due to discharge of untreated industrial effluents into water bodies is a major problem globally (Mathuthu *et al*., 1997). The problem of water pollution is experienced by both developing and developed countries. The most common types of pollutants include pathogenic organisms, oxygen demanding organic substances, plant nutrients that stimulate algal blooms, inorganic and organic toxic substances (Cornish and Mensahh, 1999).

Water pollution is either from physical, chemical or biological and it adversely impacts on aquatic organisms as well as making such water unsuitable for use in most areas of application without being treated. Many indices such as biological and chemical oxygen demand (BOD and COD), pH, dissolved oxygen (DO), salinity, total dissolved solids (TDS), total suspended solids (TSS), turbidity, electrical conductivity and heavy metals are used to ascertain the quality of water (EPA 1996; Salequzzaman *et al*., 2008).

Heavy metals that are often found in wastewater include but not limited to As, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, K, Se, Na, V and Zn. Living organisms require varying amounts of some of these metals (Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni and Zn) as nutrients (macro or micro) for proper growth. Other metals (Ag, Al, Cd, Au, Pb and Hg) have no biological role and hence are non-essential (Ayotamuno and Kogbara, 2007). Heavy metals are one of the most persistent pollutants in wastewater. Unlike organic pollutants, they cannot be degraded, but accumulate throughout the food chain, causing potential health risks and ecological disturbances. The accumulation of these metals in wastewater depends on factors such as type of industries, way of life and awareness of impact of waste disposal on the environment (Muwanga and Barifaijo, 2005).

Although iron (Fe) has not been reported to have significant health impact on human and other living organism, its concentration at elevated level makes the portability of water to be impaired, its taste uncomfortable, and it also stains laundry and plumbing materials at levels above 0.3 mg/l (WHO, 2008). Cumulative impacts are due to the gradual buildup of pollutants in receiving water, which only become apparent when a certain threshold is exceeded (Welch, 1992; Chambers *et al.*, 1997).

The water quality of receiving streams in Trans - Amadi has become a source of concern to its users. According to (Dunbabin (1992), industrial effluents are discharged into Trans-Woji streams almost exclusively without adequate treatment, resulting to nutrient enrichment, accumulation of toxic compounds in biomass and sediments. The waters are highly coloured and turbid, and they are used for cleaning, construction of buildings, and for recreational activities. These streams receive effluent from brewery, oil drilling fluids and other manufacturing industries. According to Kanu et al. (2006 and 2011), wastewater from brewery industry originates from liquors pressed from grains and yeast recovery and has the characteristic odour of fermented malt and slightly acidic, which is a source of water. However, the objective of this work is to study the transport of iron along Trans-Woji streams in Trans-Amadi industrial area of Port Harcourt, Rivers State through mathematical model.

MATERIALS AND METHODS

Sample collection and Preparation

Water samples were collected from three (3) selected streams polluted by beverage, oil drilling fluids and biscuit manufacturing industries at Trans-Woji. The samples were taken at channels where the wastewater effluents were discharged into the stream and filled into sample bottles. The collected samples were stored in refrigerator and transferred to the laboratory for analysis. The concentration of iron in the water samples was determined with the aid of Atomic Absorption Spectrophotometer (AAS) with model DR 3800- HACH according to APHA (1998). However, to fully achieve the objective of this study, the water samples were further collected at intervals of 10 meters along the surface of the stream from the waste discharged point. This was made possible through the use of boat.

Predictive Model for Heavy Metal

In order to study the transport of iron in the streams, model from an established transport equation was solved (Kashefipour and Roshanfekr, 2012; Chawla and Singh, 2014 and Patil and Chore, 2014). The solved model was used to predict the concentration of iron. The governing equation for transport of pollutant is stated in equation (1).

$$\frac{\partial C}{\partial t} = \frac{k}{\rho C_p}\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial x} \quad (1)$$

Where:

$C =$ Concentration of heavy metal (mg/l)

$k =$ Conductivity of contaminated water (J/s.m.K)

$C_p =$ Specific heat capacity of contaminated water (J/kg.K)

$\rho =$ Density of contaminated water (g/l)

$v =$ Velocity of contaminated water (m/s)

$t =$ Time of contaminant transport (s)

$x =$ Distance along the direction of transport (m)

Letting $\frac{k}{\rho C_p} = D$ (diffusivity of contaminant in water (m^2/s)), then equation (1) reduces to

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial x} \quad (2)$$

Assuming steady state transport, where differential change in concentration over time is constant, equation (2) reduces to:

$$D\frac{d^2 C}{dx^2} - v\frac{dC}{dx} = 0 \quad (3)$$

But for decreasing contaminant concentration with increase in distance of transport, concentration gradient, $\frac{dC}{dx}$ is negative, thus, equation (3) can be re-written as:

$$D\frac{d^2 C}{dx^2} + v\frac{dC}{dx} = 0 \quad (4)$$

The solution to equation (4) can be obtained from the auxiliary equation as follows.

$$Dm^2 - vm = 0 \quad (5)$$

Thus, we have:

$$m = \frac{-v \pm \sqrt{v^2}}{2D} \quad (6)$$

$$m = \frac{-v + v}{2D} = 0 \quad (7)$$

$$m = \frac{-v - v}{2D} = -\frac{v}{D} \quad (8)$$

For real and different roots, we have the solution to the model equation as:

$$C = A\exp(0)x + B\exp\left(-\frac{v}{D}x\right) \quad (9)$$

$$C = A + B\exp\left(-\frac{v}{D}x\right) \quad (10)$$

To obtain values for the constants, we use the boundary conditions as follows.

At $x = 0$; $C = C_o$

Equation (10) becomes:

$$C_o = A + B \tag{11}$$

Again, at $x = \infty$; $C = 0$

Equation (3.10) becomes:

$$A = 0 \tag{12}$$

Thus, from equation (11), we have:

$$B = C_o \tag{13}$$

Substituting equations (12) and (13) into (10) gives

$$C(x) = C_o \exp\left(-\frac{v}{D}x\right) \tag{14}$$

Equation (14) is the predictive model obtained from equation (1). However, the ratio of the stream velocity to the contaminated diffusivity was calculated by further resolving equation (14) as follows.

Taking the logarithm of equations (14) gives as follow:

$$\ln C(x) = \ln C_o - \frac{v}{D}x \tag{15}$$

A plot of $\ln C(x)$ versus x gives a slope equivalent to $\frac{v}{D}$ and intercept equal to $\ln C_o$.

RESULTS AND DISCUSSION

The physicochemical parameters obtained from the experimental analysis of Trans-Woji streams is shown in Table1. The physicochemical results show the most of the parameters such as electrical conductivity (EC), turbidity and iron are above the set limit by standard bodies (WHO, 1997 and 2008; NIS, 2007).

Table 1: Physicochemical Analysis of Waste from Receiving Water

Parameter	Site 2	Site 3	Site 4	Site 5	WHO	NIS
pH	7.24	6.6	8.07	6.34	6.0-8.5	6.0-8.5
Temp. (ºC)	26	22.4	26.7	27.3	24.28	NA
EC (µs/cm)	9986	10648	10552	10688	1000	1000
Turbidity (NTU)	27.4	29.3	31.6	36.4	5	5
BOD (mg/l)	1.4	5.2	4.3	2.6	4	NA
COD (mg/l)	71.3	78.3	64.8	79.3	NA	NA
DO (mg/l)	5.3	6.3	6.2	5.7	3-7	3-7
TSS (mg/l)	42.6	39.6	36.7	31.8	NA	NA
Salinity (mg/l)	2.1	1.3	0.9	1	NA	NA
Iron (mg/l)	6.22	5.84	5.51	6.03	0.3	NA

3.1 Iron Transport along the streams

Equation (15) was first used to determine the ratio of the streams velocity to the diffusion coefficient of iron, and then substituted into equation (14) for the prediction of iron concentration. Figure 1 shows the linear plot for data obtained from the three sites used to determine the ratio of stream velocity to diffusivity of iron concentration along the streams. The ratio as well as the correlation coefficient is shown in Table 2.

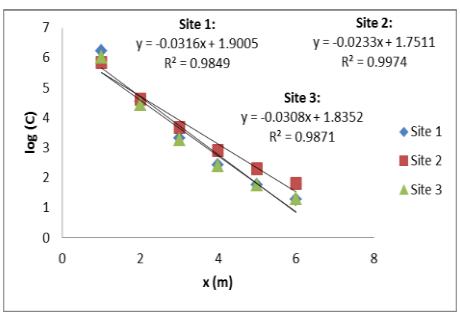

Figure 1: Plot for determination of transport coefficients

Table 2: Transport coefficient of the streams

Site	v/D	R^2
1	0.0316	0.9849
2	0.0234	0.9968
3	0.0308	0.9871

From equation (14), the predictive equations for the respective stream can be expressed as shown in Table 3.

Table 3: Predictive model

Stream	Model
1	$C_x = 6.22e^{-0.0316x}$
2	$C_x = 5.84e^{-0.0234x}$
3	$C_x = 6.03e^{-0.0308x}$

Trend of iron along the streams

The profile of iron concentration along the streams upstream as evaluated via the model is compared with the values obtained from laboratory analysis. The behaviour and concentration of iron varies from stream to stream, probably because of the nature and level of waste inhibiting it. However, the trend exhibited by iron across the stream is similar despite their variability in concentration level. The profiles comparing the measured and predicted iron concentration at each site (stream) is shown in Figures 2 to 4, while the comparison of iron concentration in the three streams is shown Figure 5.

Table 4: Measured and predicted iron concentration along the streams upstream

	Site 1		**Site 2**		**Site 3**	
x(m)	Experiment (mg/l)	Predicted (mg/l)	Experiment (mg/l)	Predicted (mg/l)	Experiment (mg/l)	Predicted (mg/l)
0	6.22	6.22	5.84	5.84	6.03	6.03
10	4.87	4.53475	4.41	4.62618	4.64	4.43154
20	3.75	3.3061	3.66	3.66464	3.53	3.25681
30	2.87	2.41035	2.94	2.90296	2.41	2.39348
40	1.92	1.75728	2.23	2.29959	2.03	1.759
50	1.26	1.28117	1.8	1.82163	1.24	1.29272
100	-	0.26389	-	0.56821	-	0.27713
200	-	0.0112	-	0.05528	-	0.01274
500	-	8.5E-07	-	5.1E-05	-	1.2E-06

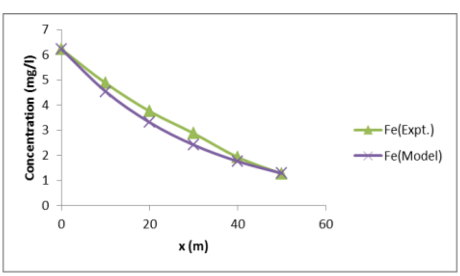

Figure 2: Measured and predicted iron concentration in site 1

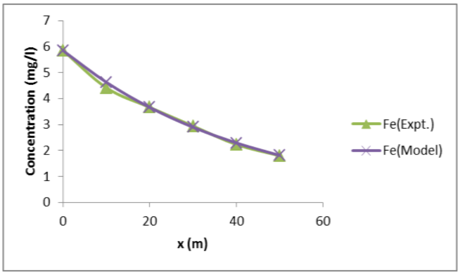

Figure 3: Measured and predicted iron concentration in site 2

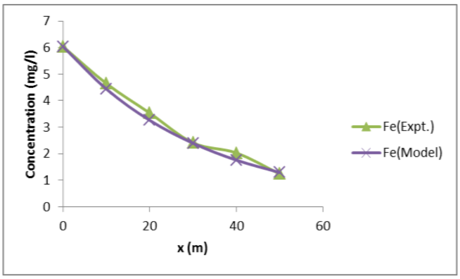

Figure 4: Measured and predicted iron concentration in site 3

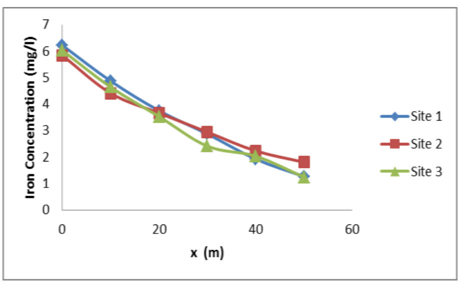

Figure 5: Comparison of iron concentration in the respective sites

Iron is one of the minerals for human nutritional requirement and its minimum daily consumption depends on age, sex and physiological status, which range from about 10 to 50mg/day (WHO, 2008). Though, there has been no reported negative health impact of iron on humans, but above 0.3 mg/l it could stain laundry and plumbing materials (WHO, 2008).

From the analysis, the concentration of iron decreases as distance away from the discharge point was increased. Thus, at 50 meters distance, the corresponding concentrations of iron were obtained are 1.26mg/l, 1.80mg/l and 1.24mg/l at site 1, site 2, and site 3 respectively (Table 4). Thus, it can be inferred that at 50 meters away from the effluent discharge point, the concentration of iron is still high above the permissible limits of 0.3mg/l (NIS, 2007; WHO, 2008). However, with the application of the model, it can be seen that the level of iron reduced below the threshold limit from about 200 meters distance from the effluent disposal point, although, at 100 meters at sites 1 and 3, the concentration of iron was slightly below the permissible limit. Therefore, the degree of agreement between measured and predicted iron concentration showed that the model can be used for the prediction of heavy metal inhibit by waste dumped in streams.

CONCLUSION

Although, the concentration of iron decreases with distance away from effluent disposal point, the level of iron measured within the waste discharge point indicates that the streams are polluted by industrial effluents. Even at 50 meters away from the effluent discharged point, the concentrations of iron in the respective stream was still above the permissible limits of 0.3mg/l set by Nigerian Industrial Standard (NIS) and World Health Organisation (WHO). However, at about 200 meters distance away from the effluent disposal point using the predictive model, the level of iron reduced below the threshold limit. Also, there was high degree of agreement between measured and predicted iron concentration, which showed that the model can be used for prediction of heavy metal inhibit by effluent wastes. Again, the concentrations iron recorded across the streams suggested that proper remedial techniques or the treatment process should be adopted and monitored by regulatory agencies to reduce the level of water pollutants.

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