Predicting the Migration of Aluminium Inhibited by Industrial Effluents in Trans Amadi Streams, Port Harcourt, Rivers State.

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Abstract
The migration of aluminium in streams upon discharge was studied through mathematical model. Three (3) streams polluted by industrial wastes from beverage, oil drilling fluids and biscuit manufacturing industries in Tras-Amadi in Port Harcourt, Rivers State of Nigeria were selected for this study. The concentration of aluminium and other parameters were measured, however, aluminium ion concentration in the streams were further measured at 10 meters intervals along the streams surface. The investigation shows industrial effluents have impact on the streams' quality. Also, it was further observed that aluminium concentration decreases with distance away from the effluent discharge point. However, from about 20 meters away from the effluent disposal point, aluminium concentration was e below the permissible limit of 0.2mg/l. The predicted concentrations were comparable to the measured values, therefore, the high degree of agreement between measured and predicted concentrations of aluminium shows the model can be used for prediction of heavy metals in water bodies.

KEYWORDS: Aluminium Migration, Modelling, Stream, Industrial Effluents

1. INTRODUCTION

The effects of metals in water and wastewater could be beneficial or dangerously toxic. While some metals are essentially useful in water, others adversely affect water consumers, wastewater treatment systems, and receiving waters. According to the U.S. Environmental Protection Agency, metals in water could be dissolved or in recoverable form, and the toxicity of metals to organisms living in water arises majorly through the absorption or uptake in dissolved form (EPA, 1996). Metals in dissolved form are mostly unacidified and pass through a 0.45 micrometer membrane filter which best represent the bioavailable fraction of metal in the water column than does the total recoverable metal, while recoverable metals are not tightly bound, and are biologically available to aquatic organisms (EPA, 1996).

Although, not all metals are acutely toxic in small concentrations, most are very toxic even at very low concentration. Such toxic metal at very low concentration include cadmium, mercury, arsenic, chromium and lead and are the most toxic to aquatic organisms. Other metals such as copper, iron, zinc and aluminium can be uncomfortable to consumers and impair on water portability (WHO, 2008). Some water quality characteristics which affect metal toxicity include temperature, pH, hardness, alkalinity, suspended solids, redox potential and dissolved organic carbon (EPA 1996; Salequzzaman *et al.*, 2008).

The impacts of water degradation can cause decrease in dissolved oxygen, as well as physical changes, release of toxic substances, bioaccumulation or increase in nutrient load (Environmental Canada, 1997). The widespread use of wastewater containing toxic wastes and the lack of adequate treatment is likely to cause increase in water borne diseases as well as rapid deterioration of water quality.

It has been observed that the release of suspended solids into receiving waters can have a number of direct and indirect environmental effects, including reduced sunlight penetration (reduced photosynthesis), physical harm to fish, and toxic effects from contaminants attached to suspended particles (Horner et al., 1994). Due to the phenomenon of bioaccumulation, certain substances which are in low concentrations or barely measurable in water and can sometimes be found in high concentrations in the tissues of plants and animals. These substances tend to be stable, and are not easily broken down by digestive processes (Environmental Canada, 1997; 1999). In some cases, through the process of biomagnification, the concentrations of some of the contaminants may be increased dramatically through passage in the food chain that is prey to predators (Chambers and Mills, 1996). Examples of such contaminants include organochlorine pesticides and heavy metals (Environmental Canada, 1997).

According to (Ogbonna *et al*., 2008) the prevalence and levels of heavy metals, and other physicochemical constituents in wastewater are encouraged by anthropogenic activities like indiscriminate disposal of waste effluents and unregulated standard for treatment processes.

Aluminium is the most abundant metallic element, constituting about 8% of the Earth's crust, and its salts are widely used in water treatment as coagulants to reduce the level of organic matter, colour, turbidity and microorganism. However, at elevated concentrations in finished water, undesirable colour and turbidity may develop (WHO, 2008). WHO further observed that aluminium and its compounds appear to be poorly absorbed when taken by humans, although the rate of absorption depends on parameters such as salt quantity used, pH (for aluminium speciation and solubility), bioavailability and dietary factors. The exposure to aluminium is assumed to causes the development or acceleration of onset of Alzheimer disease (AD) in humans (WHO, 2008).

The quality of water in Trans – Amadi, an industrial area in Port Harcourt, Rivers State of Nigeria has generated so much concern to its users (Ayotamuno *et al*., 2007). This is due to the impacts of effluents discharged by companies operating area. Dunbabin (1992) has earlier observed that industrial effluents are discharged into streams around the Trans-Amadi in an exclusive manner without adequate treatment, resulting to accumulation of toxic substances that are challenging to the health of humans either directly or indirectly upon the utilization of these waters. Because of poor water provision by government and its agencies, most people, especially the poor made use of these waters for some domestic purposes, and they are also used for construction and recreational activities. The streams considered in this study include stream receiving effluents from brewery, oil drilling fluids and biscuit manufacturing industries. Thus, the pattern of aluminium migration upon release into water bodies along the Trans-Amadi streams was studied through transport model.

2. MATERIALS AND METHODS

2.1 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-Amadi area. The samples were collected at channels where the industrial effluents were discharged into the streams and transferred into sample bottles. The collected samples were stored in refrigerator and then, transferred to the laboratory for analysis. The concentration of aluminium in the 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 with the aid of boat.

2.2 Predictive Model for Heavy Metal

The transport model was applied in this study was adopted from established transport equation (Kashefipour and Roshanfekr, 2012; Chawla and Singh, 2014 and Patil and Chore, 2014) as defined by the governing equation presented in equation (1). The model was solved as follows before being used to predict the concentration of aluminium along the distance over the stream surface.

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

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

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - v \frac{\partial C}{\partial x} \tag{2}$$

For steady state condition, the differential change in concentration of aluminium with time is constant. Therefore, equation (2) reduces to:

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

But for decrease in contaminant concentration as distance of transport increases, the concentration gradient, $\frac{dC}{dx}$ is negative, therefore, equation (3) can be re-written as:

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

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 unequal roots, the solution to the equation is given 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 $x = 0$; $C = C_o$

Hence, equation (10) becomes:

$$C_o = A + B \quad (11)$$

Again, at $x = \infty$; $C = 0$, and equation (3.10) becomes:

$$A = 0 \quad (12)$$

So, from equation (11), we have:

$$B = C_o \quad (13)$$

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

$$C = C_o e^{-\frac{v}{D}x} \quad (14)$$

Equation (14) is the predictive model. The ratio of the stream velocity to the dispersion coefficient, $\frac{v}{D}$ in the equation can be calculated by taking the logarithm of equations (14) gives as follow:

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

A plot of $\ln C(x)$ versus x will give slope equivalent to $\frac{v}{D}$ and intercept as $\ln C_o$.

3. RESULTS AND DISCUSSION

The physicochemical parameters obtained from the analysis of the streams are shown in Table1. The physicochemical results show that some of the parameters like electrical conductivity (EC), turbidity and aluminium are high compare to the limit specified by standards (WHO, 1997 and 2008; NIS, 2007).

Table 1: Physicochemical analysis of water at the effluent discharge point

Parameter	Site 1	Site 2	Site 3	WHO	NIS
pH	6.86	8.07	6.67	6.0-8.5	6.0-8.5
Temp. (ºC)	27	26.7	26.7	24.28	NA
EC (µs/cm)	10788	10552	10676	1000	1000
Turbidity (NTU)	26.3	31.6	27.8	5	5
BOD (mg/l)	1.8	4.3	1.6	4	NA
COD (mg/l)	76.7	64.8	68.3	NA	NA
DO (mg/l)	4.9	6.2	4.6	3-7	3-7
TSS (mg/l)	40.6	36.7	41.6	NA	NA
Salinity (mg/l)	1.6	0.9	1.4	NA	NA
Aluminium (mg/l)	0.82	0.73	0.67	0.2	NA

3.1 Determination of velocity to dispersion coefficient ratio

Using equation (15) the ratio of velocity to the dispersion coefficient of the streams for aluminium is determined, and thereafter substituted into equation (14) to predict the concentration of aluminium at any distance on the stream's surface. Thus, Figure 1 shows the linear plots for determination of the ratio of velocity to the dispersion coefficient of aluminium concentration in the streams, and summarised as shown in Table 2.

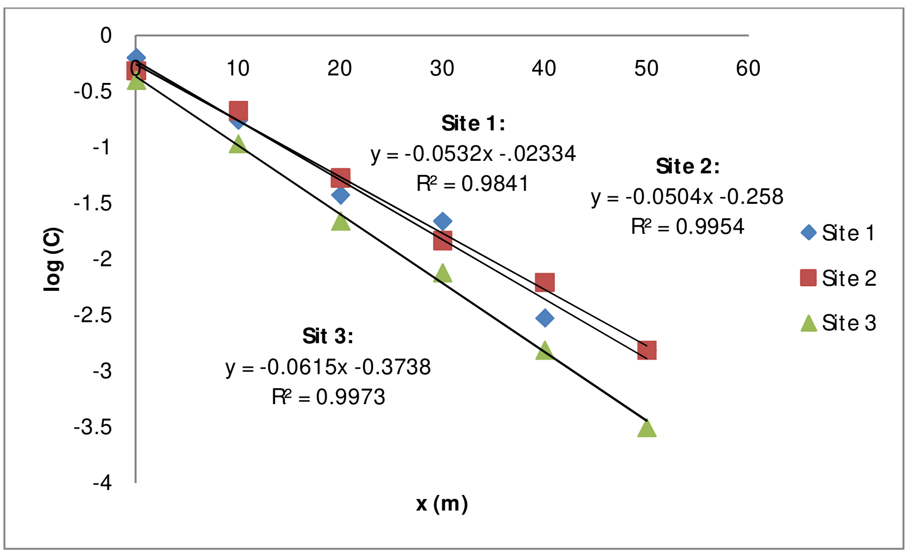

Figure 1: Plot for determination of transport coefficients

Table 2: Transport coefficient of the streams

Site	**v/D**	R^2
1	0.0532	0.9841
2	0.0504	0.9954
3	0.0615	0.9973

According to equation (14), the predictive model for aluminium in the respective stream is shown in Table 3.

Table 3: Predictive model

Stream	Model
1	$C_x = 0.82 e^{-0.0532x}$
2	$C_x = 0.73 e^{-0.0504x}$
3	$C_x = 0.67 e^{-0.0615x}$

3.2 Aluminium dispersion along the stream directional flow

The values of aluminium ion transport along the streams surface as predicted by the model is compared with those obtained from the laboratory analysis. However, the trend of aluminium ion in all the streams is similar, but there was variation in terms of magnitude from stream to stream, which can be attributed to the nature and level of waste inhibiting the aluminium ions. The profiles of aluminium ion transport along the streams surface as compared with the measured concentration are shown in Figures 2 to 4, while Figure 5 shows the comparison of aluminium ions in the three streams.

Table 4: Measured and predicted aluminium 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	0.82	0.82	0.73	0.73	0.67	0.67
10	0.47	0.48169	0.51	0.441	0.38	0.36223
20	0.24	0.28296	0.28	0.26641	0.19	0.19584
30	0.19	0.16622	0.16	0.16094	0.12	0.10588
40	0.08	0.09764	0.11	0.09723	0.06	0.05724
50	0.06	0.05736	0.06	0.05874	0.03	0.03095
60	-	0.03369	-	0.03548	-	0.01673
80	-	0.01163	-	0.01295	-	0.00489
100	-	0.00401	-	0.00473	-	0.00143

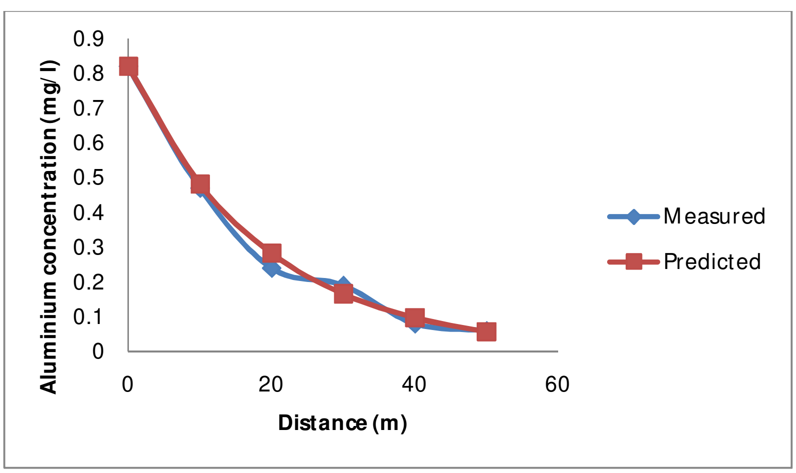

Figure 2: Measured and predicted aluminium concentration in site 1

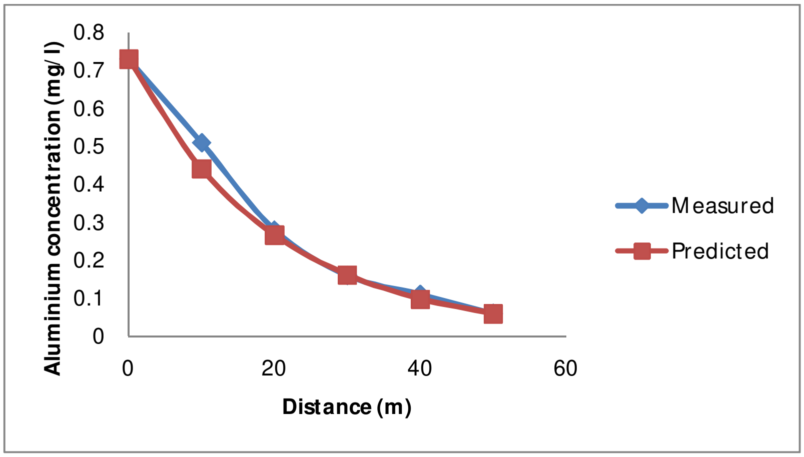

Figure 3: Measured and predicted aluminium concentration in site 2

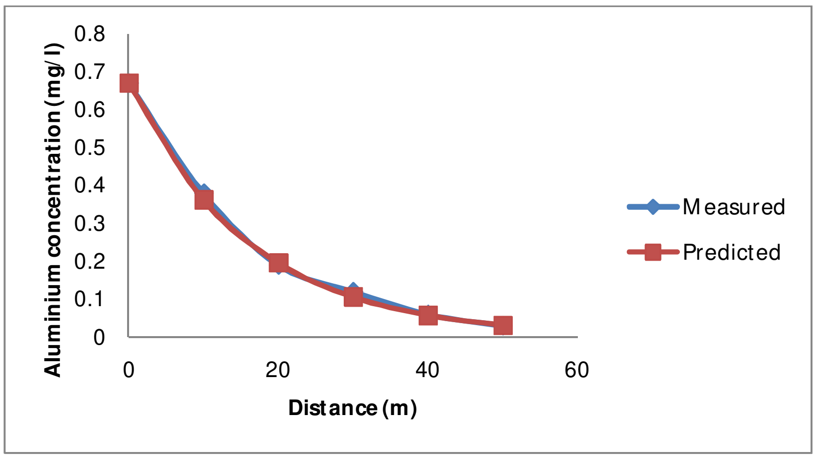

Figure 4: Measured and predicted aluminium concentration in site 3

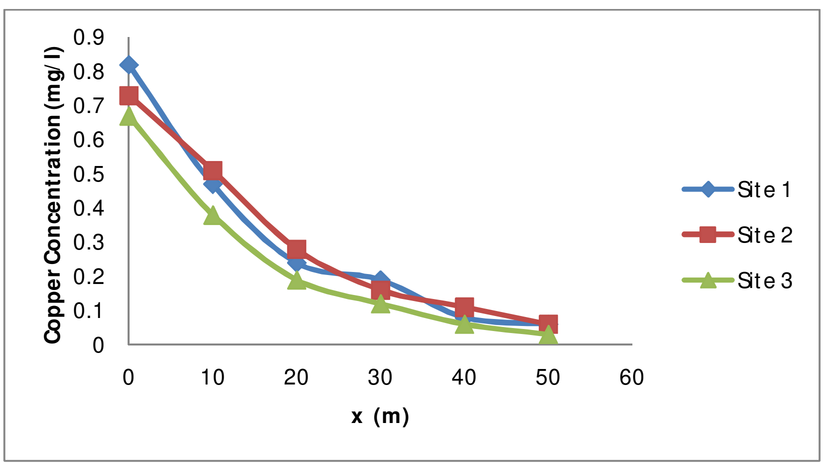

Figure 5: Comparison of copper concentration in the respective sites

The concentration of aluminium in natural waters can vary significantly depending on various physicochemical and mineralogical factors. Dissolved aluminium concentrations in waters with near-neutral pH values usually range from 0.001 to 0.05 mg/litre but rise to 0.5–1 mg/litre in more acidic waters or water rich in organic matters, and at extreme acidity of waters, dissolved aluminium concentrations could rise up to 90mg/l (WHO,1997). In drinking water, 0.2mg/l aluminium was recommended as maximum limit due to its potential neuro-degenerative disorders at excess dosage NIS (2007). Figures 2 to 4 compared the transport behaviour of aluminium obtained from the experimental analysis and the predicted values for the investigated streams receiving effluents from manufacturing and oil drilling fluid industries.

The analysis shows that aluminium concentration at the discharged points in all the streams are higher than the standard permissible limit, but decreases as distance away from the discharge point was increased to values less than permissible limit. Thus, at 50m distance, the analyzed concentrations are 0.06mg/l at site 1, 0.06mg/l at site 2 and 0.03mg/l at site 3 respectively. These are comparable to those predicted by the model as shown in Table 4 and further depicted by the profiles shown in the figures. Thus, the degree of closeness of the experimental and predicted values is an indication that the model can be used for the prediction of heavy metal inhibit by waste dumped in streams.

4. CONCLUSION

Overall, this study shows that effluents from industries have impact on the water quality of the receiving streams. This is depicted by the fact that there is a general increase in concentration of the parameters analysed as opposed to the maximum permissible limits set by WHO and NSDWQ for quality water. Although the values in some cases were lower than the maximum allowable limits by WHO (1997, 2008 and NIS, 2007), the continued discharge of un-treated effluents in the stream may result in severe accumulation of the contaminants.

Thus, while the regulatory bodies are charged to take proactive measures in tackling the ugly practice of industrial waste effluent disposal into water bodies, scientific tool such mathematical models can be applied to monitor the level of contaminants in water upon industrial effluents disposal, if sufficient input data are carefully and accurately generated.

REFERENCE

APHA (American Public Health Association) (1998). Standard Method for the Examination of Water and Waste Treatment, Washington, 143-251.

Ayotamuno, M.J. and Kogbara, R.B. (2007). Response of Environmental Characteristics to Industrialization: A Case Study of the Onne Oil and Gas, *Journal of Food and Agriculture and Environment,* 5(1), 288-289.

Chambers, P. A, Allard, M., Walker S. L, Marsalek J, Lawrence J, Servos, M, Busnarda, J., Munger, K. S, Adare, K, Jefferson, C. Kent R. A. and Wong, M. P. (1997). Impacts of Municipal Effluents on Canadian Waters: a Review. Water Qual. Res. J. Can. 32(4): 659-713.

Chawla, A. and Singh, S.K. (2014). Modelling of Contaminant Transport from Landfills, *International Journal of Engineering Science and Innovative Technology* 3 (5), 222-227.

Dunbabin, J. S. (1992). Potential use of constructed wetlands for treatment of industrial wastewaters containing metals effluent and urban pollution control manual.

Environmental Canada (1997). Review of the impacts of municipal wastewater effluents on Canadian waters and human health. Ecosystem Science Directorate, Environmental Conservation Service, Environmental Canada*,* p. 25.

Environmental Canada (1999). State of the Great Lakes. Environmental Canada and the US Environmental Protection Agency*,* p. 8.

EPA (1996). U.S. Environmental Protection Agency, American Society of Civil Engineers, and American Water Works Association. Technology Transfer Handbook: Management of Water Treatment Plan Residuals. EPA/625/R-95/008. Washington DC.

Horner, R. R, Skupien, J. J., Livingstone, E. H, Shaver, H. E. (1994). Fundamentals of urban runoff management. Technical and Institutional Issues, Terrene Institute, Washington, DC.

Kashefipour, S. M. and Roshanfekr, A. (2012). Numerical Modelling of Heavy Metals Transport Processes in Riverine Basins, *Numerical Modelling*, Retrieved from: http://www.intechopen.com/books/numerical-modelling/numerical-modelling-of-heavy-metalstransport-processes-in-riverine-basins 22nd September, 2018.

NIS (Nigerian Industrial Standards), (2007). Nigerian Standards for Drinking Water Quality, 13/14 Victoria Arobieke Street, Off Admiralty Way, Lekki Peninsula Scheme 1, Lekki, Lagos, Nigeria, 17-19.

Ogbonna, D. N., Simeon, N., Chilaka, S. N. & Gobo, A. E. (2008)., Effects of Poor Waste Disposal Practices and Perennial Flooding on Groundwater in Port Harcourt, *Journal of Environmental Science,* 4(2), 59-65.

Patil, S.B. & Chore, H.S. (2014). Contaminant Transport through Porous Media: An Overview of Experimental and Numerical Studies, *Advances in Environmental Research*, 3 (1), 45-69.

Salequzzaman, M., Tariqul, I. S. M., Tasnuva, A., Kashem, M. A. and Mahedi Al Masud, M., (2008). Environmental impact of sugar industry - a case study on Kushtia Sugar Mills in Bangladesh: Khulna: Green World Foundation

WHO (1997) Guidelines for Drinking Water Quality. Vol.3 (2nd Edition) WHO Press, 20 Avenue Appia, 1211 Geneva 27, Switzerland, 317, 390 and 392.

WHO (World Health Organization), (2008). Guidelines for Drinking-Water Quality: Incorporating the first and second, Addenda, Volume 1 Recommendations, 3rd Edition, WHO Press, 20 Avenue Appia, 1211 Geneva 27, Switzerland, 317, 390 and 392.