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Modelling of Copper ion in Contaminated Streams Inhibited by Industrial Effluent

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Abstract

In this study, the dispersion of copper in streams polluted by industrial effluent was investigated via mathematical model. Three streams located in Tras-Amadi area in Port Harcourt, Rivers State of Nigeria, which are polluted by effluents from beverage, oil drilling fluids and biscuit manufacturing industries. The concentration of copper and other parameters were measured. However, the concentration of copper was further measured at every 10 meters intervals along the streams surface. It was shown that industrial effluents impair on the quality of the streams, however, the concentration of copper reduces as distance from the effluent disposal point was increased. And after 50 meters away from the effluent disposal point, the concentration of copper reduces even further below the permissible limits of 1.0 mg/l, as predicted by the model across the respective streams. Hence, from the high prediction accuracy and the degree of agreement between measured and predicted copper ion, the model can be applied for prediction of heavy metals in contaminated water bodies.

Key words: Copper, Modelling, Stream, Effluent Wastes

INTRODUCTION

Water is natural resources that have wide application in all sectors. Because of industrial revolution and the attitude of humans towards handling of wastes, water bodies have been susceptible to pollution from chemical and biological substances, which change the quality of water, thereby adversely impacting on the environment negatively.

The quality of wastewater effluents is responsible for the degradation of its receiving water bodies, such as lakes, rivers, streams, etc. The potential deleterious effects of polluted wastewater effluents on the quality of receiving water bodies are numerous and depend on the volume of discharge, the chemical and microbiological concentration or composition (Owili, 2003).

Eutrophication of water sources may also create environmental conditions that favour the growth of toxin producing cyanobacteria (Eynard et al., 2000). Chronic exposure to such toxins produced by these organisms can cause gastroenteritis, liver damage, nervous system impairment, skin irritation and liver cancer in animals (EPA, 2000; WHO, 2006). In extension, recreational water users and anyone else coming into contact with the infected water is at risk (Resource Quality Services, 2004).

The impacts of such degradation may result in decreased levels of dissolved oxygen, physical changes to receiving waters, release of toxic substances, bioaccumulation in aquatic life and increased nutrient loads (Environmental Canada, 1997). Wastewater is a complex resource, with both advantages and inconveniences for its use. Wastewater and its nutrient contents can be used for crop production, thus providing significant benefits to the farming communities and society in general. However, wastewater use can also impose negative impacts on communities and the ecosystems. The widespread use of wastewater containing toxic wastes and the lack of adequate finances for treatment is likely to cause increase in wastewater borne diseases beside environmental degradation. Some of the harmful effects of contaminated wastewater effluents could manifest after several years, while others manifest in just few days of exposure (Environmental Canada, 1999; WHO, 2006).

The toxic impacts from wastewater effluents may be acute or cumulative, and the acute impacts are generally due to high levels of ammonia, chlorine, high loads of oxygen-demanding materials, or toxic concentrations of heavy metals and organic contaminants, while the cumulative impacts are due to the gradual build-up of pollutants in receiving water, which only become apparent when a certain threshold is exceeded (Welch, 1992; Chambers *et al*., 1997).

In assessing the quality of water, certain parameters are used as indicator, by checking if they exceed the permissible limit set by local and internal bodies charged with the responsibility of regulating water resources such the Nigerian Industrial Standards in Nigeria (NIS, 2007) and World Health Organisation (WHO, 1997, 2006 and 2008). Such indicating parameters include pH, dissolved oxygen, BOD, COD, total dissolved solids (TDS), total suspended solids (TSS), turbidity, electrical conductivity and of course, heavy metals (EPA, 1996; Smith and Davies-Calley, 2001; Gray, 2002; Mosley *et al*., 2004; Tariq *et al*., 2006; Salequzzaman *et al*., 2008). Most heavy metals are required for healthy living at certain amounts and these include Ca, Fe, K, Mg, Mn, Na, and Zn, while others such as Ag, Al, Cd, Au, Pb and Hg have no biological role and hence are non-essential (Horner *et al*., 1994; Muwanga and Barifaijo, 2006). Heavy metals are one of the most persistent pollutants in wastewater. Unlike organic pollutants, they cannot be degraded, but accumulate throughout the food chain, producing potential human health risks and ecological disturbances (Fakayode, 2005). In this study, the transport of copper along streams receiving industrial wastes was studied through a mathematical model, which will serve as a tool for analysis of copper dispersion in contaminated stream.

MATERIALS AND METHODS

Sample collection and Preparation

Water samples were collected from three (3) selected streams polluted by brewery, oil drilling fluids and beverage industries at Trans-Amadi industrial area in Port Harcourt, Rivers State of Nigeria. The water samples were collected from the wastewater effluents discharge points and at every interval of 10 meters along the surface of the stream from the discharged point with aid of boat. The samples were put into sample bottles, stored in refrigerator to avoid alteration due to atmospheric effect before being analysed in the laboratory. The concentration of copper was determined with the aid of Atomic

Absorption Spectrophotometer (AAS) with model DR 3800- HACH according to APHA (1998).

Predictive Model for Heavy Metal

The model used to study the dispersion of copper along the streams followed established transport equation (Chawla and Singh, 2014; Patil and Chore, 2014). The model was solved and used to predict the concentration of copper. The model equation is stated in equation (1).

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

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 $\frac{k}{\rho C_p} = D$ (dispersion coefficient (m^2/s)), then equation (1) gives

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

For steady state condition, the differential change in concentration over time is constant; hence, equation (2) reduces to:

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

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:

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

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

$$Dm^2 - vm = 0 \tag{5}$$

Thus, we have:

$$m = \frac{-v \pm \sqrt{v^2}}{2D} \tag{6}$$

$$m = \frac{-v + v}{2D} = 0 \tag{7}$$

$$m = \frac{-v - v}{2D} = -\frac{v}{D} \tag{8}$$

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

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

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

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, v to the dispersion coefficient, D was calculated by further solving equation (14).

Thus, taking the logarithm of equations (14) gives as follow:

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

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 laboratory analysis of the three streams are shown in Table1. The physicochemical analysis shows that most of the parameters such as electrical conductivity (EC), turbidity and copper are above the permissible limits set by standards (WHO, 1997 and 2008; NIS, 2007).

Table 1: Physicochemical Analysis of Waste from Receiving Water

Parameter	Site 1	Site 2	Site 3	WHO	NIS
pH	6.86	8.07	8.24	6.0-8.5	6.0-8.5
Temp. (°C)	27	26.7	24.2	24.28	NA
EC (μs/cm)	10788	10552	9868	1000	1000
Turbidity (NTU)	26.3	31.6	30.8	5	5
BOD (mg/l)	1.8	4.3	3.1	4	NA
COD (mg/l)	76.7	64.8	66.3	NA	NA
DO (mg/l)	4.9	6.2	5.5	3-7	3-7
TSS (mg/l)	40.6	36.7	35.3	NA	NA
Salinity (mg/l)	1.6	0.9	1.3	NA	NA
Copper (mg/l)	3.47	2.44	3.41	1.0	NA

Dispersion of copper along the streams

The dispersion coefficient of copper was determined using equation (15). Thus, the coefficient of x in the linear regression equation in the graph in Figure 1 represents the ratio of the streams velocity to the dispersion coefficient of copper, which was equated to the ratio upon which the dispersion coefficient was obtained and then, substituted into equation (14) for the prediction of copper concentration at any point on stream. Figure 1 shows the linear plots for the three sites. Thus, from the evaluation, the ratio and correlation coefficient of data for the respective sites is shown in Table 2. Also, from equation (14) after the determination of the dispersion coefficient or directly applying the ratio of the streams velocity to the dispersion coefficient of copper, the predictive equation for the respective stream is then used as expressed in shown in Table 3.

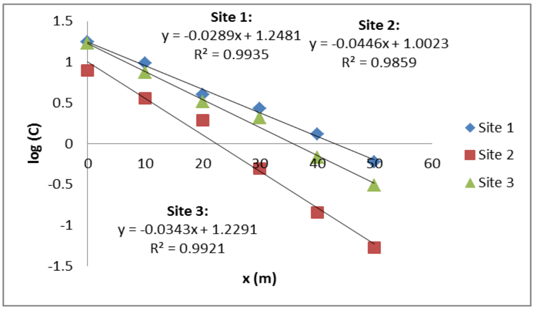

Figure 1: Plot for determination of dispersion coefficient

Table 2: Transport coefficient of the streams

Site	v/D	R^2
1	0.0289	0.9935
2	0.0446	0.9859
3	0.0343	0.9921

Table 3: Predictive model

Stream	Model
1	$C_x = 3.47e^{-0.0289x}$
2	$C_x = 2.44e^{-0.0446x}$
3	$C_x = 3.41e^{-0.0343x}$

Table 4: Measured and predicted copper 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	3.47	3.47	2.44	2.44	3.41	3.41
10	2.68	2.59907	1.75	1.56205	2.38	2.41987
20	1.82	1.94674	1.33	1.0000	1.66	1.71723
30	1.54	1.45813	0.74	0.64018	1.37	1.21861
40	1.12	1.09216	0.43	0.40983	0.84	0.86477
50	0.8	0.81804	0.28	0.26237	0.6	0.61368
100	-	0.19285	-	0.02821	-	0.11044
150	-	0.04546	-	0.00303	-	0.01988
200	-	0.01072	-	0.00033	-	0.00358

Profile of copper ion along the streams

The profile of iron concentration along the streams upstream evaluated through the model is compared with experimental values. Thus, the concentration of copper ion varies from stream to stream, and this is probably as a result of the characteristics and amount of waste inhibiting copper. Despite the variability in concentration of copper, the pattern of copper dispersion exhibited across the streams is similar. However, the profiles of the measured and predicted copper concentration for each site (stream) is shown in Figures 2 to 4, while the comparison of copper concentration for the three streams is shown Figure 5.

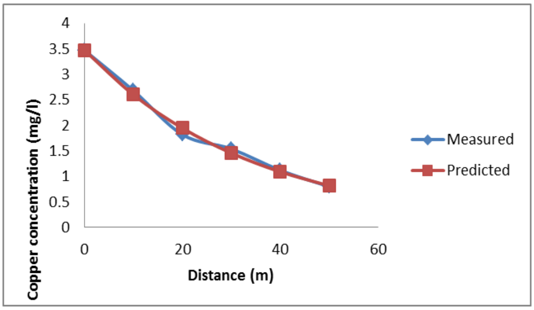

Figure 2: Measured and predicted copper concentration in site 1

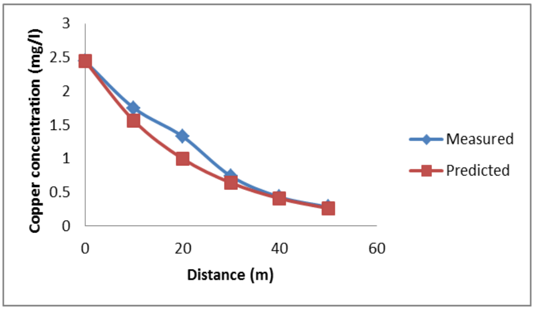

Figure 3: Measured and predicted copper concentration in site 2

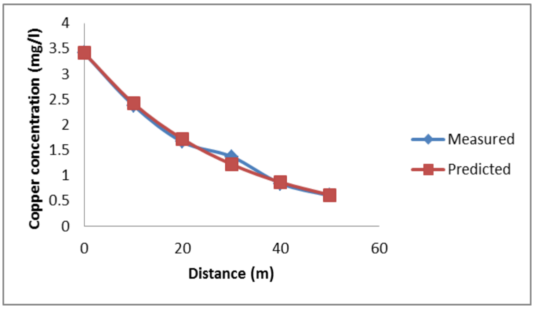

Figure 4: Measured and predicted copper concentration in site 3

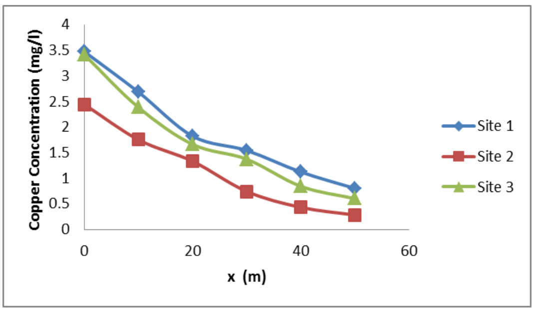

Figure 5: Comparison of copper concentration in the respective sites

Figures 1 to 4 show the transport behaviour or trend of copper, Cu ion for each of the receiving stream for model and the experiment. This was to show clearly how the profiles of copper obtained from the experiment and the model compared. Although, copper is essential for plant and animal nutrition, at elevated quantity, it could make water distasteful to drink and very large prolonged dosage may result to liver damage according to WHO (2008). Copper is acutely toxic to most forms of aquatic life at relatively low concentrations. From the experimental analysis, the concentration of copper obtained at the discharged point (Table 4) was above the maximum permissible limit of 1.0 mg/l set by WHO (1997) in all the sampling sites, especially for drinking water requirement (NIS, 2007 and WHO, 2008). However, the concentration of copper decreased from the initial value detected at the discharged point to levels below the standard limits in all the streams. Thus, at 50 meters away from the source the concentration detected was 0.80mg/l, 0.28mg/l and 0.60 mg/l for sites 1, 2 and 3 respectively, which reduced even further beyond 50 meters away from the effluent discharge point as predicted by the model.

CONCLUSION

This study shows that the concentration of copper reduces as distance from the effluent disposal point was increased. Also, the amount of copper measured within the waste discharge point indicates that the streams are polluted by industrial effluents, but pollution from copper ion decline below the permissible limits of 1.0 mg/l set by World Health Organisation (WHO) after it has dispersed up to 50 meters away from the effluent discharged point, and decreased even further from 100 to 200 meters as predicted by the model across the respective streams. Meanwhile, there was high degree of agreement between measured and predicted concentration of copper, indicating the applicability of model for prediction of heavy metal inhibit by industrial effluent or any other waste discharge into water bodies.

REFERENCES

1. APHA, (1998). Standard Methods for Examination of Water and Waste water. American Public Health Association. Washington.
2. 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., Wong, M. P. (1997). Impacts of Municipal Effluents on Canadian Waters: a Review. Water Qual. Res. J. Can. 32(4): 659-713
3. Chawla, A. & Singh, S.K. (2014). Modelling of Contaminant Transport from Landfills, *International Journal of Engineering Science and Innovative Technology* 3 (5), 222-227.
4. 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.
5. Environmental Canada (1999). State of the Great Lakes. Environmental Canada and the US Environmental Protection Agency, p. 8.
6. 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.

7. EPA (2000). Nutrient criteria technical guidance manual- rivers and streams. EPA-822-B-00-002. Washington DC
8. Eynard, F., Mez. K., Walther J. L. (2000). Risk of cyanobacterial toxins in Riga waters (LATVIA). Water Res. 30(11): 2979-2988.
9. Fakayode, S. O. (2005) Impact of Industrial Effluent on Water Quality of Receiving Alaro River in Ibadan, Nigeria. *AJEAM-RAGEE*, 10, 1-3
10. Gray, N. F. (1989). *Biology of Water Treatment*, New York: Oxford University Press, Hamilton, New Zealand
11. Horner, R.R, Skupien, J.J., Livingstone, E.H. and Shaver, H.E. (1994). Fundamentals of urban runoff management, Technical and Institutional Issues, Terrene Institute, Washington, DC
12. Mosley, L., Sarabjeet S. and Aalbersberg, B. (2004): Water quality monitoring in Pacific Island countries. Handbook for water quality managers & laboratories, Public Health officers, water engineers and suppliers, Environmental Protection Agencies and all those organizations involved in water quality monitoring (1st Edition). 43 p; 30 cm, ISSN: 1605-4377: SOPAC, The University of the South Pacific. Suva - Fiji Islands
13. Muwanga, A. and Barifaijo, E. (2006): Impact of industrial activities on heavy metal loading and their physico-chemical effects on wetlands of the Lake Victoria basin (Uganda).
14. 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.
15. Owuli, M. A. (2003). Assesment of impact of sewage effluents on coastal water quality in Hafnarfjordur, Iceland. The United Nations Fishery Training Program, Final Report.
16. 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.

17. Resource Quality Services (2004). Eutrophication and toxic cyanobacteria. Department of Water Affairs and Forestry, South Africa. Available from www.dwaf.gov.za/WQS/eutrophication/ toxalga.html. Accessed 14/03/2007.
18. 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
19. Smith, D. G. and Davies-Colley, R. J. (2001). If visual water clarity is the issue, then why not measure it?: New York City Department of Environmental Protection, Bureau of Water Supply, National Institute of Water and Atmospheric Research.
20. Tariq, M., Ali, M. and Shah, Z. (2006). Characteristics of industrial effluents and their possible impacts on quality of underground water; Soil Science Society of Pakistan Department of Soil & Environmental Sciences, NWFP Agricultural University, Peshawar
21. Welch, E. B. (1992). Ecological effects of wastewater. Applied Limnology and Pollutant Effects, 2nd edition. Chapman and Hall, New York, p. 45.
22. WHO (1997) Guidelines for Drinking Water Quality. Vol.3. Geneva, Switzerland (2nd Edition)
23. WHO, (World Health Organization) (2006) International Standards for Drinking Water, 3rd ed. WHO, Geneva.
24. 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.