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Predicting Leachate Effluent Contamination from Kaduna, Yola and Maiduguri Landfill Sites

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Abstract: Integrated Landfill Sites for Kaduna, Yola and Maiduguri were investigated for potential contamination of the underlying aquifers by modeling the leachate effluent discharges over years using the analytical solution of the mass balance equation. Results indicated a significant threat to underlying aquifer and a high degree of pollution of the community borehole water supply. The study recommends provision of protective membrane on the walls of the landfill sites and development of leachate management scheme.

Key words: Leachate, effluent, contamination, landfill, predicting, aquifers

INTRODUCTION

Waste disposal system has been a major problem in major cities of Nigeria and indiscriminate dumping of solid and liquid wastes has constituted major obstruction to flow of runoff water in drainages causing floods. The Ogunpa flood disaster of 1986 in Ibadan, Oyo State in the southwestern Nigeria and Kaduna 2003 flood disasters are combination of waste management problems and high rainfall. The construction of these integrated waste management facilities will not only improve environmental health but also reduces associated problems.

Kaduna, Yola and Maiduguri are the capital cities of Kaduna, Adamawa and Borno States of Nigeria respectively and are among the major cities where Integrated Waste Management Facilities (IWMF) are planned for construction in Nigeria. These cities have large concentration of industries such as agricultural, food and beverages, automobiles, textiles, oil mills, paper manufacturing and conversion, hospitality businesses, plastic, tanneries, flour mills, breweries, poultry feed mills, pharmaceuticals, industrial chemical, fertilizer, markets, printing and publishing, refinery/petrochemical plants and academic institutions. Large quantities of wastes are generated from these establishments and their nature and characteristics are so diverse and coupled with poor management practices, they are currently an eye sore in our cities thereby constituting environmental health hazard.

The integrated waste management system planned for some cities in Nigeria is focused on the establishment of sanitary landfills. Sanitary landfills are engineered disposal systems that are operated in accordance with environmental protection standards (USEPA, 1994). Several studies on waste management in Nigeria have been published, but most of them are limited in scope and extent and they rarely include prediction of leachate migration and pollution. They include Fulani and Abumere (1983), Massey (1992), Beecroft *et al.* (1987), Ademoroti (1988) Egboka *et al.* (1989) and Bichi (2000) among others.

This study therefore, examines the impacts of the proposed sanitary landfills at Kaduna, Yola and Maiduguri on their immediate environments. The study modeled the concentrations of the leachate from these landfills over a period of time to predict their impacts on the groundwater quality.

MATERIALS AND METHODS

The method of investigation was divided into the following stages at the three locations:

- Solid waste sampling and categorization from fifteen sites strategically located within each of the cities.
- The chemical characteristics of the waste were determined by chemical digestion of representative soil samples taken at 0-30cm beneath the heap of waste at each of the fifteen solid waste dump sites considered for each city.
- Permeability tests were also carried out on soil samples taken from six pits dug to 0.5-1.0m deep at each of the sanitary landfill sites.
- Geophysical investigation using the Vertical Electrical Sounding (VES) was conducted at the sanitary

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landfill sites to obtain subsurface information, specifically vertical succession of lithology, depth to Basement rocks and water table position from the surface.

- The 50-year migration of the leachate constituents into the groundwater systems was investigated and modeled using the analytical solution of the mass balance equation, Eq. (1) and (2), for transport of dissolved reactive constituents in saturated isotropic porous media (Baetsle, 1969).

$$\frac{\partial C}{\partial t}=\left[\frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_z\frac{\partial C}{\partial z}\right)\right]-\left[\frac{\partial}{\partial x}\bar{V}_xC+\frac{\partial}{\partial y}\bar{V}_yC+\frac{\partial}{\partial z}\bar{V}_zC\right] \quad (1)$$

$$\frac{\partial C}{\partial t}=\left[D_x\frac{\partial^2 C}{\partial x^2}+D_y\frac{\partial^2 C}{\partial y^2}+D_z\frac{\partial^2 C}{\partial z^2}\right]-\left[\bar{V}_x\frac{\partial C}{\partial x}+\bar{V}_y\frac{\partial C}{\partial y}+\bar{V}_z\frac{\partial C}{\partial z}\right] \quad (2)$$

Baestle (1969) provide an analytical solution to Eq. (2) as contamination mass is transported through the flow system, the concentration distribution of the contamination mass at time t is given by:

$$\frac{C}{C_O}=\frac{1}{2}\left[\operatorname{erfc}\frac{\left(x-\frac{Vt}{R}\right)}{2\sqrt{\frac{Dt}{R}}}+\exp\left(\frac{Vx}{D}\right)\operatorname{erfc}\frac{\left(x+\frac{Vt}{R}\right)}{2\sqrt{\frac{Dt}{R}}}\right] \quad (3)$$

Where Co and C are the initial and final concentration of contaminant in water.

D is the coefficient of longitudinal dispersion in x-direction.
V is the average pore-water velocity.
R is the retardation factor.
X is the distance irrigated by contaminant along flow path and t is the time.

RESULTS AND DISCUSSION

The solid waste sampling and categorization results as presented in Table 1 indicated that food wastes constitute a major part of the wastes generated in all the cities resulting in high concentration of biogas emissions from the dump sites. As presented in the table, metallic waste is still very significant in the wastes generated despite the activities of the scavengers who collect them for re-use by the steel mills in the country. Plastic films wastes especially polyethylene are another significant element in the waste constituting environmental nuisance and clog drainage channels.

Table 1: Comparison of some solid waste generation (%) of study areas

Composition	Maiduguri 2002	Yola 2002	Kaduna 2002
Total paper	5.73	6.5	7.2
Food waste	46.04	44.12	49.73
Textiles	3.97	4.21	4.5
Ashes/dust	12.72	13.05	9.64
Metal (Ferrous and non frerrous	10.68	9.41	9.32
Plastic and plastic films	12.71	13.50	9.94
Glass	5.75	6.84	6.43
Biodegradable total	68.46	67.88	71.07
Non biodegradable total	29.14	29.75	25.69
Miscellaneous	2.4	2.37	3.24

Table 2: Maximum leachate concentration compared with upper leachate limits and W.H.O. standard

Substance	Maximum leachate Conc. obtained	*Standard leachate upper limits	+WHO maximum guideline value for drinking water
BODS	500.5	54610	6.0
COD	750.7	8950	10.0
PH	8.8	8.5	6.5-8.5
T.D.S	2000	.-	500
E.C. (Ms/CM)	2400	.-	-
Total Hardness	1100	.-	100
Acidity	280.5	.-	500
Alkalinity	460.3	.-	500
Sulphate	268.1	1826	250
Chloride	2241	2800	250
Nitrate	2.0	1416	10 as N; 45 a NO_3^-
Bicarbonate	800.4	20850	500
Carbonate	120.0	22800	500
Calcium	45	4080	200
Magnesium	13.0	15600	150
Iron (as Fe2+)	1.80	5500	0.3
Manganese	0.0	1400	0.1
Chromium	0.15	-	0.05
Sodium	181	7700	200
Potassium	650	3770	15
Lead	-	5.0	0.05
Copper	-	9.9	1.0
Zinc	-	1000	5.0

+ Source: World Health Organization, (1971), * Source: After Bouwer (1978)

Comparative analysis of chemical composition of the digested soil samples collected from beneath solid waste dump sites with the standard upper limits and world Health Organization (W.H.O.) International Standards for drinking water are presented in Table 2.

Table 2 shows that the parameters whose maximum values exceeded the W.H.O. international Drinking Water standard are BOD, COD, TDS, total hardness, potassium, Iron, Chromium, bicarbonate, sulphate and chloride. However, the values obtained for calcium, magnesium, nitrate and carbonate are within permissible limits for drinking water. Consequently with soil permeability coefficients ranging between 1 $.44\times10^{-4}$ and 3.6×10^{-2} mm s^{-1} in Kaduna and between 2.81×10^{-3} and 4.54×10^{-1}mm s^{-1} at Yola and Maiduguri, the hydraulic resistance to the flow of these contaminants to underlying aquifers is higher in Kaduna and lower in Yola and Maiduguri.

Kaduna and Yola have Basement Complex geology while Maiduguri lies on the Chad sedimentary basin. From the geophysical data interpretation 5-6 layers were identified in the areas. While the depth to Basement rock was found to be between 28 m and 50m in Kaduna and Yola, the Basement rock could not be reached at Maiduguri. But generally the geologic setting of the sites was found to be suitable for sanitary landfill location.

Equation (3) was initialized with known variables and programmed on the Microsoft Excel to provide the changes in concentration C of the leachate in the aquifer and in the surrounding location or constituents using the standard upper limits given in Table 2.The contaminants were considered to be non-reactive, which presented the worst condition for the modeling. The maximum concentration of sixteen water quality indices were simulated for varying periods of t ranging from 25 days to 25years during which leachate is expected to have been formed, migrate towards and contaminate the underlying aquifer. The model result indicated that because of the low permeability of the landfill site in Kaduna, it would take about 500 days for leachate flow to reach the bedrock located averagely at about 50m below ground level, 420 days to reach a nearby stream northward and about 10 years to reach a nearest community borehole. However, for Yola and Maiduguri where the soil permeability is slightly high to medium, the leachate concentration could reach the bedrock at non-tolerant level as early as 50 days; 100 days at the nearest community borehole, 4-5 years at Maiduguri township and between 17 years and 20 years at Yola township.

CONCLUSION

The analysis results indicated a significant threat to the underlying aquifers and for a community that is dependent upon groundwater sources for water supply, protective linings must be provided on the walls of the landfill sites. A leachate management scheme must also be developed to further reduce the degree of contamination of the underlying aquifer. This includes regular monitoring of the effluent concentrations in the community boreholes, adequate funding of facilities maintenance and establishment of adequate health care services for the area.

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