Predicting Surface Water Contamination from the Kaduna, Yola and Maiduguri Landfill Sites

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Abstract: Surface water contamination from effluents from solid waste dump site is a phenomenon in Nigeria and the government planned to construct Central Integrated Waste Management Facilities in most of the State Capitals of Nigeria in order to control the menace of flooding arising from blockage of drainages and littering of the environment by solid wastes. This paper modeled the impact of the proposed Sanitary Landfills sites contained in the facilities on their immediate basin's surface water resources using the US Soil Conservation Service Model and the Streeter-Phelps dissolved oxygen balance equation. The results show that the critical dissolved oxygen concentration could be as bad as 730 to 786 mg/l and could occur within 1.98 to 2.17 days of first contact with the stream which will begin to show sign of recovery as early as the 25th day of first contact. [Researcher. 2009;1(6):63-68]. (ISSN: 1553-9865)

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Introduction

Indiscriminate dumping of solid and liquid wastes has constituted a major obstruction to the flow of runoff water in drainages in urban settlements of Nigeria. The flood events of Ogunpa 1986, Kaduna 2003, Lagos 2007, and Abeokuta 2007 are typical solid waste induced flooding. Overrun of solid waste dump sites by runoff waters and subsequent discharge into river systems has also led to source contamination of the urban water supply systems.

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 construction of integrated waste management facilities in these cities will not only improve environmental health but also reduces associated problems.

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 (1983), Ademoroti (1988) Egboka et al, (1989) and Bichi (2000) among others.

The sites for these Integrated Waste Management Facilities (IWMF) were located on the outskirt and upstream of these cities. Between the sites and the cities, there are smaller communities within the same river basin that depend on the river water for their domestic and agricultural water supply. These facilities would therefore constitute potential danger to human and animal health if the leachate inflow into the surface water bodies is not properly managed.

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

Method of Investigation

The capacity of the surface water environment to assimilate contaminants and pollution is a function of both the source quality, the nature of the physical, chemical and biological properties of the contaminants and the re-aeration capacity of the system. In order to ensure that the loading of pollutants from the landfill sites in the receiving waters does not exceed its capacity, and that the quality of water in the river systems remain satisfactory to the downstream users, it therefore became important to examine:

- Whether the volume of available water running between the landfill site and the stream as well as the flow rate of the stream is sufficient for effective dilution; and
- Whether the degree of dilution and dispersion to be achieved while in transport will be sufficient to prevent adverse effects to both the aquatic ecosystem of the receiving water and the human population downstream and around the landfill sites.

It was also critical to examine runoff flows and volume under storm events. Direct precipitation, especially high energy raindrops, can penetrate the landfills and promote the reaction of storm water with various constituents of the landfill.

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 where the wastes would be moved to the sanitary landfill sites.
- 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.
- The effect of contaminants in surface water is measured by the dissolved oxygen deficit in the water, therefore the Biochemical oxygen Demand (BOD) is the most critical parameter considered in this model. To this effect, the surface water contamination was investigated by modeling the dissolved oxygen deficits consequent to:
  - ✓ leachate spring discharge of effluents from the Landfill sites and

  - ✓ contaminants dissolved by overland flow over the landfill sites arriving the nearby stream channel,

to determine the natural stream water recovery time using the Streeter-Phelps equation (1):

$$D_t = \frac{K_D L}{K_R - K_D}(10^{-K_D t} - 10^{-K_R t}) + D_O 10^{-K_R t}$$

(1)

Where:

Dt = dissolved oxygen deficit at time, t (mg/l)

L = ultimate first stage BOD at point of waste discharge (mg/l)

D_o = initial oxygen deficit, (mg/l)

K_D = deoxygenation coefficient

K_R = reoxygenation coefficient.

The time t_m at which the minimum dissolved oxygen occurs can be obtained from equation (2) given as follows

$$t_m = \frac{1}{K_R - K_D}\log\left[\left(\frac{K_D L - K_R D_O + K_D D_O}{K_D L}\right)\frac{K_R}{K_D}\right]$$

(2)

and the corresponding critical oxygen deficit, D_c determined by equation (3)

$$D_C = \frac{K_D L}{K_R}10^{-K_D t_m}$$

(3)

Estimation of Volume of Runoff

The United States soil conservation services (SCS) model is one of the rainfall-runoff models popularly used to estimate the runoff contribution form a unit rainfall. The SCS model used in this study is based on a hydrological soil parameter known as runoff curve number, type of soil and infiltration characteristics, and antecedent moisture condition. The SCS model (Schwab et al, 1981) is given by equation (4).

$$Q = \frac{(P - 0.2S)^2}{(P + 0.85S)}$$

(4)

Q = total direct surface runoff in depth, in mm

P = Rainfall intensity, in mm

S = Maximum potential abstraction of water by soil, mm, given by equation (5)

$$S = \frac{25400}{N} - 254$$

(5)

N = runoff curve number for hydrological soil – cover complexes.

When storm water runs through landfills, many of its constituents will move into solution, some bio-accumulate in the water while others remain in suspension as it flows towards the receiving surface water downstream. On arrival at the recipient stream, it combines with existing contaminants in flow and moves through various channel physical conditions to ensure proper dilution. The contaminated water is further diluted at confluences or where effluent flow from the groundwater recharges the stream flow.

Considering the contaminants individually as tracer of concentration Cs at each landfill site flowing overland at the rate of Qs and discharging into the adjoining river with existing tracer concentration C_R flowing at the rate of Q_R, the concentration C of the resulting mixture in the streamflow is given by equation (6)

$$C = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R}$$

(6)

The processes of re-oxygenation and deoxygenation progress simultaneously as the stream flows downstream towards the cities, and the Streeter-Phelps equation was used at five days interval to simulate the variation in the dissolved oxygen deficit concentration.

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.

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 (WHO) 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 x 10^{-4} and 3.6 x 10^{-2} mm/s in Kaduna, and between 2.81 x 10^{-3} and 4.54 x 10^{-1}mm/s 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.

Modeled dissolved oxygen deficit concentrations are presented in Table 3 while the critical dissolved oxygen and time of occurrences are presented in Table 4. The results presented in Tables 3 & 4 shows that the critical dissolved oxygen concentration could be very bad, ranging between 730 and 786 mg/l at the location 1 in each City due to the washing of the landfill constituents into the adjoining river/stream. This situation occur within 1.98 to 2.17 days of contact with the water body at the stream will begin to show sign of recovery as early as the 25th day of first contact at location 1. The recovery time is expected to be much more shorter due to more dilution from the tributaries, but could be more critical during the dry season.

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 & Non Frerrous	10.68	9.41	9.32
Plastic & 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 (mg/l)

Substance	Maximum Leachate Conc. Obtained	*Standard Leachate Upper Limits	+WHO Maximum Guideline Value for Drinking Water
BOD_5	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. (μs/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 Bower, 1978

Table 3: Modeled Dissolved Oxygen Deficit Concentration

Time (days)	K A D U N A		Y O L A		M A I D U G U R I	
	Sample Location 1	Sample Location 2	Sample Location1	Sample Location 2	Sample Location 1	Sample Location 2
5	436.85	289.91	447.16	268.91	No immediate Surface Water Source	
10	73.56	77.41	87.93	89.81		
15	9.63	19.52	13.31	28.48		
20	1.16	4.90	1.83	9.0		
25	0.13	1.23	0.24	2.85		
30	0.015	0.31	0.03	0.9		
35	0.0017	0.078	0.004	0.28		
40	0.00020	0.020	0.0005	0.09		
45	0.000022	0.0049	0.0000641	0.28		
50	0.0000025	0.0012	0.000008	0.09		
55	0.0000003	0.00031	0.000001	0.003		
60	0	0.00008	-	-		

Table 4: Critical Dissolved Oxygen and Time of Occurrence

Parameter	K A D U N A		Y O L A		M A I D U G U R I	
	Sample Location 1	Sample Location 2	Sample Location1	Sample Location 2	Sample Location 1	Sample Location 2
Dc (mg/l)	786.133	474.614	730.58	390.29	No immediate Surface Water Source	
Tm (days)	1.984	1.984	2.13	2.17		

Conclusion and Recommendations

From this study, it can be inferred that surface water pollution is expected to be active for about 25days at each location, after which the stream is able to recover naturally. Minimization of leachate generation through the control of surface infiltration water into the landfill is recommended as an effective management strategy. Containment of leachate within the landfill through the use of double or composite liner systems, perimeter and base blinding with low permeability bund walls are recommended as effective construction control techniques. In order to prevent outbreak of disease epidemic, alternative sources of water supply should be provided for the communities adjoining the sites because low flow Biochemical Oxygen Demand conditions would be critical. The results presented herein are predictive, based on existing limited data and expected waste composition. It is highly recommended that parameter measurement indices be initiated immediately at the commencement of the project for future model study and analysis.

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