

Geochemical Assessment of a Proposed Landfill in Ibadan, Southwestern Nigeria.

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ABSTRACT

Evaluation of a site in Ibadan, southwestern part of Nigeria, was undertaken using geochemical methods to investigate properties of residual soils for waste reception, generate baseline information on soil vulnerability, soil/waste materials compatibility, groundwater chemistry and hydraulics necessary in assessing the suitability of the site for waste disposal.

Geochemical and physico-chemical parameters of soils from test pits namely, pH, Cation Exchange Capacity (CEC), Total Organic Carbon (TOC) and clay mineralogy including elemental composition in groundwater were determined. Total Dissolved Solids (TDS), Electrical Conductivity (EC), as well as, temperature of well waters were determined *in-situ* using well parameters.

The pH of 5.8 - 7.1 showed that the soils can accommodate wastes rich in heavy metals. However the TOC and CEC of the soil in the present study need to be enhanced. X-ray diffraction showed abundance of kaolinite in the soils. This was indicative of a well drained environment. Physicochemical parameters of groundwater and baseline elemental composition (K^+ , Mg^{2+} , Si^{4+} , Ca^{2+} , Na^+ , Mn^{2+} , Ba^{2+} , Sr^{2+} , Cl^- and NO_3^-) are lower than both the World Health Organization (WHO) and Standards Organization of Nigeria (SON) drinking water standards. The cumulative effect of rainfall, evaporation, temperature and relative humidity favors the establishment of a landfill system.

(Keywords: geochemical, groundwater, waste disposal)

INTRODUCTION

Solid waste products arise from our way of life. The exploration for raw materials is the beginning

of solid waste generation. Thereafter solid wastes are generated at every step in the process as raw materials are converted to goods for consumption. In the developed parts of the world, waste management and environmental sustainability have been quite successful. As is common in most developing economies, Nigerians seem to see pollution by domestic and industrial wastes as a necessary outcome of development.

According to Nwankwo (1994), growing populations, rising incomes and changing consumption patterns combine to complicate solid-waste problems in Nigeria. Ogbonna et al. (2002) opined that apart from various diseases and toxic conditions inherent in and derivable from wastes products, the presence of waste degrades the aesthetic value of the environment. Environment and health hazards associated with illegal open dumping of waste are well known (Langer, 1995). For instance, deposited wastes undergo changes through chemical reactions and large volumes of toxic gases may be generated on decomposition.

Groundwater contamination by landfill leachate is increasingly recognized as a serious problem as described by several authors (Hussain et al., 1989; Al-Muzaini and Muslmani, 1994; Onianwa et al., 1995; Asiwaju-Bello and Akande, 2001; Olayinka and Olayiwola, 2001; and Abimbola et al., 2005). Shonuga (2008), underscores the importance of the issue of waste disposal in the country by postulating that indiscriminate disposal of waste pollutes both surface and underground water resources as gases such as carbon monoxide and nitrogen generated by decomposition of organic wastes create health and fire hazards.

Fields and Lindsey (1975) opined that landfills should be sited to take advantage of geological factors which are responsible for optimum

attenuation of waste. Such factors include topography, geology (rock type, geologic structure, weathering characteristics), hydrology (permeability, depth to water table, direction and rate of flow), climate (precipitation) and composition of soils (which affect pH and sorptive capacities). It is thus obvious that any site chosen for waste disposal must be hydrogeochemically suitable and environmentally safe.

Oyediran and Adeyemi (2005) evaluated a location for waste disposal using geophysical and geotechnical methods. While this method produced useful results, it was observed that the work did not consider waste/materials compatibility and waste reception hence the need to obtain geochemical and hydrogeological baseline information prior to waste disposal. This study was therefore aimed at determining the suitability of the study area geochemically and hydrogeologically as a landfill site by undertaken the characterization of the soil and groundwater in the vicinity of the site, determination of soil/waste materials compatibility and generation of baseline pre-dumping information.

STUDY AREA

The study area falls within the Basement Complex terrain of southwestern Nigeria (Figure 1). The Basement Complex rocks consist of crystalline igneous and metamorphic rocks, which form part of the African crystalline shield with the rocks belonging to the youngest of the three major provinces of the West African Craton. These rocks occur either exposed or covered by a shallow mantle of superficial deposits. They are loosely categorized into three main subdivisions namely the migmatite–gneiss complex, the schist belt and the Pan-African (ca. 600 ma) older granite series (Elueze, 2000).

The area lies between longitudes 3° 52' and 3° 54' East of the Greenwich meridian and latitudes 7° 27' and 7° 28' North of the Equator. The average elevation of the area is about 230m above sea level (Faniran, 1994) and is easily accessible by a network of roads (Figure 2).

The climate is influenced by two major air masses controlling the seasons (wet and dry). The monthly summary of weather data for year 2003-2007 (International Institute of Tropical Agriculture, 2007) indicates that month of June (232.54 mm) had the highest peak, while the average annual

rainfall between 2003 and 2007 was found to be 1245.92 mm. North – East trade winds, dominate the dry season.

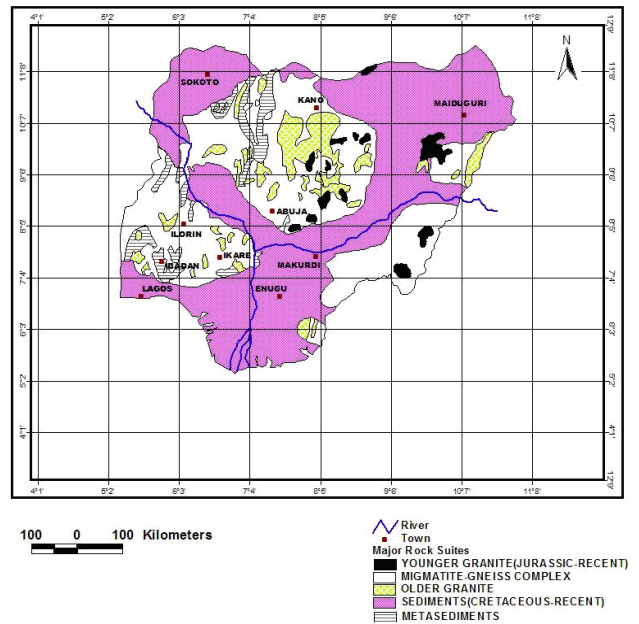


Figure 1: Generalized Geological Map of Nigeria (Geological Survey of Nigeria, 2004).

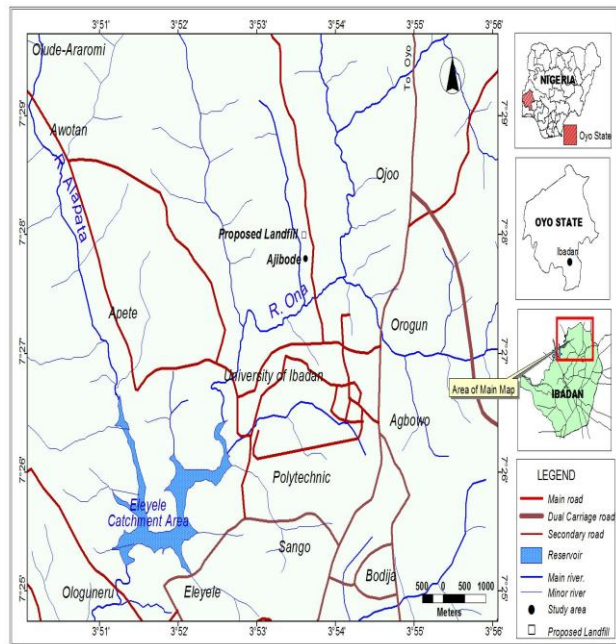


Figure 2: Map of the Study Area.

MATERIALS AND METHODS

Thirty-five (35) soil samples were collected from seven (7) test pits at depth intervals of 0.50m up to a depth of 4.00m in each pit to determine most suitable depth for waste reception and to assess waste/soil compatibility. Physico-chemical and geochemical studies of soil samples was undertaken using parameters relevant for landfill siting which include pH, Total Organic Carbon (TOC) and Cation Exchange Capacity (CEC). Clay mineralogy was determined using X-ray Diffraction (XRD) with the Rigaku D/Max-III C X-ray diffractometer.

Thereafter three (3) wells were dug at the sampling site to determine the ground water flow direction and hydraulic gradient. Eighteen (18) water samples obtained from location wells (LW) and wells found in the closest community (CW) about 1.85km away from the proposed site were subjected to physico-chemical analyses to determine pH and temperature using a DIGITAL SATO SK-632 ph/temperature meter while total dissolved solids and conductivity were determined using a COND. METER MODEL CM-1K.

Laboratory chemical analyses using the ICP-OES to determine the concentration of elements in the water samples at the Activation Laboratories Limited, Ancaster Ontario, Canada were conducted with a Perkin Elmer OPTIMA 3000 Radial ICP for the 37 element suite. Furthermore the Nitrate and Chloride concentrations of water samples were determined with a Dionex DX-120 ion chromatography system. The results obtained from the on-site wells were correlated with those determined from the nearest existing wells to establish pre-dumping baseline data for the area. In addition, data on flow velocity and bottom leakage potential were generated. Weather data for the study area over a five year period from 2003-2007 were studied to help with understanding the climate and hydrology and enable further characterization of the study area.

RESULTS AND DISCUSSION

Soil Geochemistry

The suitability of soil for use in a landfill depends to a great extent on the physico-chemical parameters of the soil and the type of waste to be disposed. Sitig (1979) noted that parameters that

influence the mobility of pollutants like heavy metals and some organic pollutants include: pH, TOC and CEC.

pH

pH values (Table 1) range from 5.79 – 6.15. pH showed no regular trend with depth for all the pits. (Figure 3). This is probably because it is a parameter that can be influenced with the minutest conditions on the field. Most metals in the pH range 6.0 - 9.0 are not always in the free form according to Porteus (1985). The mobility of most heavy metals that pollute the environment increases as acidity (lower pH) increases because most of their salts dissolve at lower pH.

The pH range of the soils in the present study is a strong indication that the soil is suitable as land fill for wastes that are rich in heavy metals since their mobility would not be supported by pH as most of them will be in insoluble form hence they are unavailable to the environmental media. This implies that most of the metals especially heavy metals will be retained by the soil.

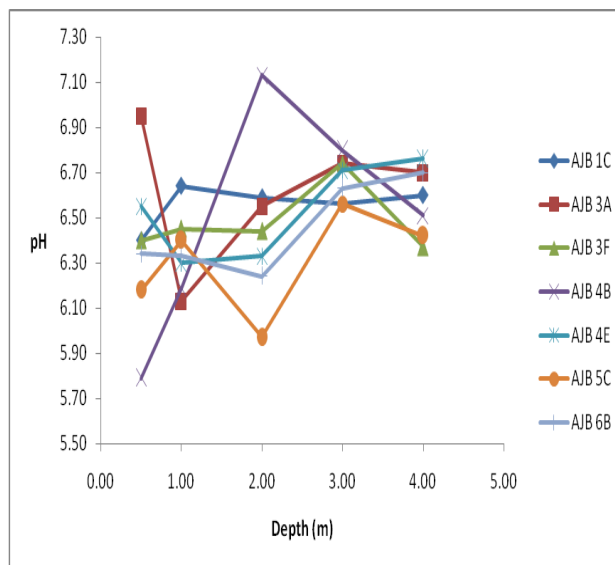


Figure 3: pH Trend of the Studied Soils with Depth.

Total Organic Carbon (TOC)

Total Organic Carbon (TOC) values (Table 1) of the soils range from Below Detection Limit (BDL) to 0.44 %.

Table 1: Values of pH, TOC, and CEC of the Studied Soils.

PITS	DEPTH (m)	pH	TOC (%)	CEC (cmolc/kg)
AJB 1C	0.50	6.40	0.575	7.34
	1.00	6.64	0.335	2.54
	2.00	6.59	0.22	5.17
	3.00	6.56	0.17	3.22
	4.00	6.60	BDL	3.30
AJB 3A	0.50	6.95	0.086	2.69
	1.00	6.13	0.402	2.96
	2.00	6.55	0.077	3.05
	3.00	6.74	BDL	3.03
	4.00	6.70	BDL	3.31
AJB 3F	0.50	6.40	0.373	2.93
	1.00	6.45	0.373	3.79
	2.00	6.44	0.192	2.39
	3.00	6.74	0.067	3.27
	4.00	6.37	BDL	3.27
AJB 4B	0.50	5.79	0.326	1.57
	1.00	6.19	0.134	2.80
	2.00	7.13	0.038	3.21
	3.00	6.80	BDL	2.86
	4.00	6.51	BDL	3.27
AJB 4E	0.50	6.55	0.44	1.54
	1.00	6.30	0.153	1.48
	2.00	6.33	0.421	3.31
	3.00	6.71	0.057	3.24
	4.00	6.76	BDL	3.29
AJB 5C	0.50	6.18	0.402	2.14
	1.00	6.40	0.077	2.85
	2.00	5.97	0.207	3.07
	3.00	6.56	0.201	3.78
	4.00	6.42	0.038	3.02
AJB 6B	0.50	6.34	0.306	1.45
	1.00	6.33	0.421	2.73
	2.00	6.24	0.182	2.84
	3.00	6.63	0.153	3.11
	4.00	6.70	0.018	5.09

BDL = Below Detection Limit

Organic matter content in lateritic soils is generally low, usually below 2% of the top soil, and can be as low as 0.2-0.6% in typical lateritic gravel soil profile in West Africa (Gidigasu, 1976).

TOC in the soil in this study is therefore low. Low organic matter content is characteristic of lateritic soils but it may be higher in tropical black clay profiles. TOC showed a steady decrease with depth in AJB 1C, AJB 3F, AJB 4B and AJB 6B, while it fluctuated at some depths for pits AJB 3A, AJB 4E and AJB 5C (Figure 4).

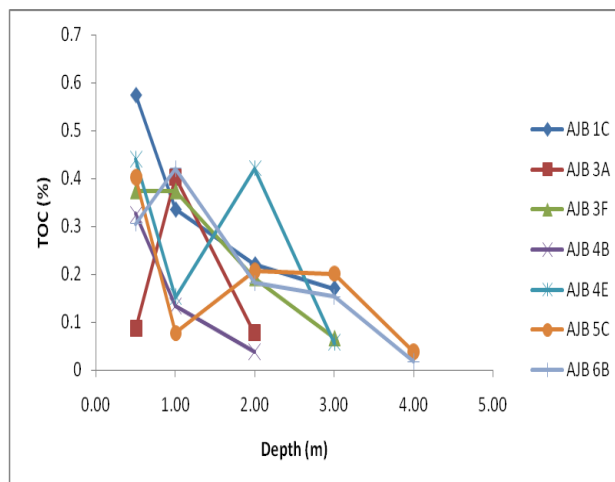


Figure 4: TOC Trend of Studied Soils with Depth.

From all indications, TOC showed an expected trend, because organic matter is mostly concentrated within the top layer of soil. With an increase in depth, organics tend to be trapped within the soil layers thereby preventing them from getting to sub soil.

Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) refers to the quantity of negative charges in soil existing on the surfaces of clay and organic matter. The negative charges attract positively charged ions, or cations, hence the name 'Cation Exchange Capacity'. The values of the CEC (Table 1) for the soils range from 1.48 to 7.34 cmolc/kg.

Variation in CEC in all the pits was minimal. This could probably be due to evenly distributed parent material that formed the soil. CEC or non-specific adsorption mechanisms are complex because it is dependent on factors like pH. However, in general terms, the higher the CEC of a soil, the more the active sites exchanges could occur, and the more the retention expected. For cations of the same valence, the adsorption strength should be determined mainly by the hydrated radius of the ions (Ji and Li, 1997). In other words, a soil with high TOC and CEC always has high retention capacity for heavy metals. This is because organic carbon (matter) contains humic materials with highly complex functional groups, which have ability to complex metals thereby retaining them in the topsoil (Evans, 1989).

The TOC and CEC of the soil in the present study need to be enhanced for its suitability as landfill. Biodegradable waste high in organics could be suitable in the landfill as the waste would improve the TOC of the soil.

Clay Mineralogy

The results from the determination of clay minerals present in the soil shows Kaolinite to be the most predominant (Table 2). A few of the diffractograms are displayed in Figures 5-7.

Clay minerals, owing to their mode of formation, strongly reflect the character of their source materials and the climatic conditions that existed during weathering (Friedman and Sanders, 1978). Gidigas (1976); Ola (1982) and Mesida (1985) observed that the amount and types of clay minerals in lateritic soils affect their geotechnical characteristics. The affinity of a soil for water also depends on its predominant clay mineral content.

The implication of the determined mineralogical composition is that the soil would exhibit low to moderate shrinkage on drying and low to moderate expansion on wetting since kaolinite has the least affinity for water among the clay minerals.

The presence of the different types of clay minerals in the studied soils implies that the soil from the study area are likely to perform well the two main functions of containment and attenuation expected of natural landfill soils (Allen, 2000).

Containment requires that all liquid and gaseous emissions produced within the landfill are contained within the landfill and collected for treatment while attenuation allows the liquid wastes to migrate from the landfill, employing the natural geological/hydrogeological characteristics of the subsurface to moderate and attenuate pollutants.

The “activity” of the soils is generally low and the low “activity” in the Basement-complex derived soils is attributed to the predominance of kaolinite in the soil. Such soil will not exhibit any appreciable swelling potential since kaolinite has the least affinity for water among the clay minerals (Ola, 1982). As kaolinite is often associated with a well drained environment, it can also be inferred that the study area is a well

drained environment; hence the soils could be used as materials for the base of landfills.

According to vanOlphen (1977), the least activity (sorptive capacity) of the major clay mineral groups, and also the lowest CEC are possessed by the kandites. High swelling clays such as the smectites are more prone to mineral transformations and collapse than mixed clay mineral assemblages and the low swelling illite and kaolinite clay groups (Batchelder et al, 1998a).

Table 2: Mineral Content of the Studied Soils.

PITS	DEPTH (m)	MINERAL CONTENT (%)						
		M	V	S	I	K	Q	F
AJB 1C	0.50	0	6	0	0	69	20	5
	1.00	0	9	0	0	56	30	5
	2.00	0	5	0	0	60	25	10
	3.00	0	4	0	0	54	30	12
	4.00	0	4	0	0	70	21	5
AJB 3A	0.50	0	6	0	0	81	12	1
	1.00	4	4	0	0	75	13	4
	2.00	6	6	0	0	72	14	2
	3.00	0	7	0	0	78	13	2
	4.00	0	0	9	0	62	19	10
AJB 3F	0.50	0	7	0	0	73	20	0
	1.00	0	3	0	0	66	23	8
	2.00	3	4	4	0	69	20	0
	3.00	0	3	3	0	70	23	4
	4.00	0	6	3	0	66	20	5
AJB 4B	0.50	0	6	0	4	70	20	0
	1.00	0	7	0	0	58	25	10
	2.00	4	5	0	0	69	20	2
	3.00	0	3	3	0	71	22	1
	4.00	0	0	5	0	64	20	11
AJB 4E	0.50	0	4	0	0	68	24	4
	1.00	0	6	5	0	71	15	3
	2.00	6	0	0	0	67	27	0
	3.00	0	5	0	0	65	29	1
	4.00	0	4	0	3	70	15	8
AJB 5C	0.50	0	4	0	0	67	21	8
	1.00	5	0	4	0	68	21	2
	2.00	5	0	0	5	65	18	7
	3.00	4	5		0	65	16	10
	4.00	1	5	0	0	75	19	0
AJB 6B	0.50	1	4	0	3	70	19	3
	1.00	6	6	0	0	70	18	0
	2.00	0	5	0	5	73	12	0
	3.00	0	6	0	3	67	24	0
	4.00	0	3	0	5	75	17	0

K = Kaolinite; V = Vermiculite; S = Sepiolite; I = Illite; Q = Quartz; F = Feldspar; M = Montmorillonite.

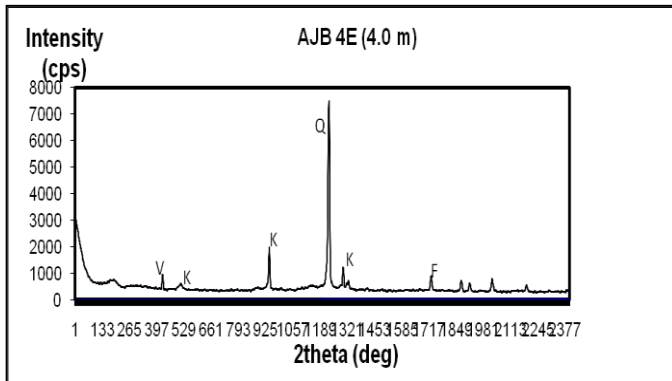


Figure 5: Diffractogram for AJB 4E at 4.0m.

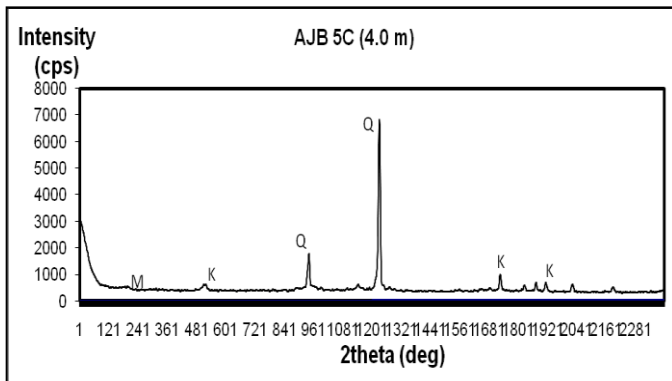


Figure 6: Diffractogram for AJB 5C at 4.0m.

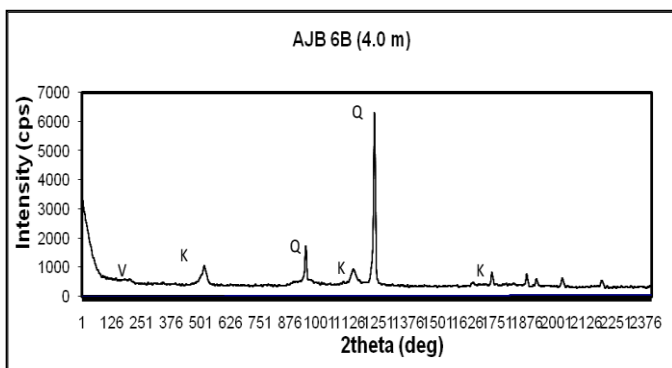


Figure 7: Diffractogram for AJB 6B at 4.0m.

Water Geochemistry

Major and Trace Element Composition: A summary of the results obtained from the water analysis is shown in Table 3. The major elements analyzed for were Na, Ca, Mg, K, Fe, P, Al, and Si. The analysis shows that the concentration of Na ranges from 7.30 – 11.00 mg/l; Ca from 6.40 – 11.90mg/l; Mg, from 3.10 – 8.20 mg/l; K, from 1.80 – 2.30 mg/l; Fe, from 0.27 – 0.72 mg/l; P, from 0.02 – 0.08 mg/l; Al, from 0.30 to 0.90 mg/l and Si, from 12.70 – 17.90 mg/l for samples collected from location wells, while the concentration of Na ranges from 38.30 – 43.50 mg/l; Ca, from 17.30 – 59.40 mg/l; Mg, from 7.20 – 23.10 mg/l; K, from 2.30 – 4.90 mg/l; Fe, from 0.03 – 0.71 mg/l; P, from 0.02 – 0.03 mg/l; Al, from 0.10 to 0.30 mg/l and Si, from 31.10 – 35.10 mg/l for samples collected from community wells.

Average K, Mg, Ca, Na and Si concentrations in water from community wells were found to be higher than those for location wells. In terms of abundance K, Mg, Ca and Na are next in abundance to Si in the location wells while for the community wells K, Mg, Si and Ca are next in abundance to Na. The concentrations of Al, Fe and P have been found to be too low in both well sets.

A strong positive correlation of 0.89 exists between the plots of Electrical conductivity and Na concentration. The Mg concentrations from all the wells were higher than the SON (2007) drinking water standard. This may be as a result of the bedrock type which contains abundant ferromagnesian minerals. Al concentration in the location wells are higher than the limits accepted for both the WHO (2006) and SON (2007) standards. This phenomenon may be attributed to the sampling depth of the water and the weathering processes resulting in soil formation. The location wells have an average depth of 10.81m while the community wells have an average depth of 4.6 m.

For the trace elements (Mn, Ba, Co, Cu, Sr, and Zn) analyzed, the concentration of Mn ranges from 0.13 – 0.20 mg/l, that of Ba, 0.05 – 0.08 mg/l, Cu, BDL – 0.015 mg/l, Sr, 0.04 – 0.08 mg/l and Zn, 0.03 – 0.06mg/l while Co is constant at 0.002mg/l for location wells. For the community wells the ranges are as follows: Mn, 0.26 – 0.27 mg/l, Ba, 0.13 – 0.18 mg/l, Co, 0.002 – 0.006, Cu, BDL – 0.003 mg/l, Sr, 0.13 – 0.26 mg/l and Zn, 0.02 – 0.13mg/l.

Table 3: Summary of Water Chemistry in the Study Area.

ELEMENTS (mg/l)	PROPOSED SITE				SURROUNDING COMMUNITY				WHO	SON
	LW 1	LW 2	LW 3	RANGE	CW 1	CW 2	CW 3	RANGE		
Al	0.90	0.50	0.30	0.30 - 0.90	0.30	0.10	0.10	0.10 - 0.30	0.20	0.20
K	1.80	2.30	2.20	1.80 - 2.30	2.30	4.90	4.30	2.30 - 4.90		
Mg	3.10	8.20	4.10	3.10 - 8.20	7.20	17.00	23.10	7.20 - 23.10		0.20
Si	12.70	17.90	13.30	12.70 - 17.90	35.10	31.70	31.10	31.10 - 35.10		
Ca	6.40	11.90	8.60	6.40 - 11.90	17.30	59.40	38.30	17.30 - 59.40		
Fe	0.38	0.27	0.72	0.27 - 0.72	0.71	0.04	0.03	0.03 - 0.71	0.30	0.30
Na	7.30	11.00	10.00	7.30 - 11.00	38.70	43.50	38.30	38.30 - 43.50	200	200
P	0.08	0.02	0.05	0.02 - 0.08	0.03	0.02	0.02	0.02 - 0.03		
Mn	0.13	0.20	0.13	0.13 - 0.20	0.26	0.27	0.26	0.26 - 0.27	0.50	0.20
Ba	0.05	0.08	0.05	0.05 - 0.08	0.13	0.18	0.18	0.13 - 0.18	0.20	0.70
Co	0.002	0.002	0.002	0.002	0.006	0.002	0.002	0.002 - 0.006		
Cu	BDL	0.015	0.003	BDL - 0.015	0.003	BDL	BDL	BDL - 0.003	2.00	1.00
Sr	0.04	0.08	0.05	0.04 - 0.08	0.13	0.26	0.25	0.13 - 0.26		
Zn	0.03	0.03	0.06	0.03 - 0.06	0.13	0.02	0.04	0.02 - 0.13	3.00	3.00
ANIONS										
Cl ⁻	2.11	6.13	1.57	1.57 - 6.13	18.9	45.6	35.2	18.9 - 45.6	250	250
NO ₃ ⁻	0.81	0.20	0.17	0.17 - 0.81	0.23	6.39	4.39	0.23 - 6.39		50
PHYSICAL PARAMETERS										
PH	6.34	6.20	6.61	6.20 - 6.61	6.62	6.62	6.94	6.62 - 6.94	6.5 - 8.5	6.5 - 8.5
EC(μs/cm)	170	100	90	90 - 170	300	610	540	300 - 610	250	1000
TDS(mg/l)	0.0009	0.0003	0.0005	0.0003 - 0.0009	0.0015	0.0031	0.0027	0.0015 - 0.0031	500	500
TEMP (°C)	25	25	26	25 - 26	27	29	28.5	27 - 29		

BDL = Below Detection Limits, LW = Location Well, CW = Community Well, WHO = World Health Organization, SON = Standards Organization of Nigeria.

The trace elements concentration in all the water samples were found to be lower than the limits set by both the WHO (2006) and SON (2007) with the exception of Mn where concentration in water samples from the community wells was found to be higher than the SON (2007) standards for drinking water. In all cases, the concentrations of trace elements in water samples from community wells are higher than those in the samples from the location wells. This may be linked to variation in the degree of weathering of bedrock. In terms of relative abundance Mn is the most abundant trace elements in the water samples from both location and community wells.

Cl⁻ and NO₃⁻ Concentration: Cl⁻ and NO₃⁻ were the anions analyzed for in the water samples. The concentration of Cl⁻ in the water samples from both location and community wells in the study area range between 1.57mg/l and 6.13mg/l and between 18.9mg/l and 45.6mg/l, respectively.

These values are much lower than both the WHO (2006) and SON (2007) drinking water standards of 250 mg/l. The maximum limit of 250mg/l set for chloride is the level above which the taste of the water may become objectionable to the consumer.

NO₃⁻ is the more stable oxidized form of combined nitrogen in most environmental media. Most nitrogenous materials in natural waters tend to be converted to nitrate, and therefore, all sources of combined nitrogen (particularly organic nitrogen and ammonia) should be considered as potential nitrate sources. Major sources of nitrates in groundwater can be grouped into four categories namely, waste materials, natural sources, fertilizer (crop agriculture) and irrigated agricultural practices (Canter, 1996).

NO₃⁻ concentration in the water samples from both location and community wells in the study

area range between 0.17mg/l and 0.81mg/l and 0.23mg/l and 6.39mg/l, respectively. These values are very low when compared to both the WHO (2006) and SON (2007) standards of 45mg/l and 50mg/l respectively for drinking water. This is an indication that the groundwater is not polluted. Furthermore correlation between Cl^- and TDS shows strong positive correlation of 0.97 (direct and good) which is an indication that there is no visible pollution of the water resources of the study area (Ariyo et al., 2005).

It can be concluded that the anion concentration of Cl^- and NO_3^- in the studied water samples are very low and do not indicate any pollution of the water and thus will not pose any health threat to the inhabitants of the study area.

Physical Parameters

The depth to water level in the hand dug wells used in this study varies from 8.00m to 9.25m while the well depth varies from 10.45m to 13.00m.

The electrical conductivity values of water samples range from 90 $\mu\text{s}/\text{cm}$ to 170 $\mu\text{s}/\text{cm}$ for location wells (LW) and 300 $\mu\text{s}/\text{cm}$ to 610 $\mu\text{s}/\text{cm}$ for community wells (CW). Conductivity is a reflection of the total ions (Total Dissolved Solids). Samples from the community wells show higher values than the values for samples from location wells. This is further corroborated by the high Na concentration values for samples from the community wells as compared to the location wells. Electrical conductivity of water samples from all the wells fall within the SON (2007) limits but only samples from location wells fall within the WHO (2006) standard.

The pH values of water samples from location wells range from 6.20 to 6.61 while for samples from the community wells range from 6.62 to 6.94. The results indicate water that is slightly acidic. All the values fall within the acceptable limits for both the WHO (2006) and SON (2007) standards.

Temperature ranges from 25 °C to 26 °C in water samples from location wells and 27 °C to 29 °C in samples from community wells. Values obtained for water samples from the community wells are thus higher than those from the location wells.

In terms of TDS, location wells display values ranging from 0.0003 mg/l to 0.0009 mg/l while community wells display values ranging from 0.0015 mg/l to 0.0031 mg/l. The values for all the water samples fall below the limits stipulated by the WHO (2006) and SON (2007) standards. However water samples from the community wells have higher TDS than those from the location wells. This may be attributed to anthropogenic influence of human activities rather than geogenic influence.

Groundwater Hydraulics

Hydrologically, the direction of slope of the water table is important because it indicates the direction of the groundwater flow. The knowledge of the direction of the groundwater movement has become increasingly important because of the danger of contaminating groundwater supplies. Groundwater moves in the direction of decreasing total head.

Physical measurements were obtained for wells dug at the sampling locations to help with the determination of the groundwater flow metrics of the study area. The ground water flow direction was found to be in the North - South direction and the hydraulic gradient was calculated to be 17.70 m/km.

Weather Condition of the Study Area

A summary of the monthly rainfall data (Table 4) over a five year period (2003-2007) shows that the highest amount of precipitation is noticed between the months of June and October with a drop in August.

Table 4. Monthly and Annual Summary of Weather Data from 2003 to 2007 (IITA, 2007).

MONTH	TOTAL RAINFALL (mm)	No. OF RAINY DAYS	FOURIER INDEX	YEAR	ANNUAL RAINFALL (mm)	No. OF RAINY DAYS	TOTAL EVAPORATION (mm)	TEMPERATURE (°C)	
								MINIMUM	MAXIMUM
JANUARY	15.66	1.00	0.0629	2003	1342.00	96	1275.30	21.90	31.20
FEBRUARY	26.72	1.60	0.1072						
MARCH	35.46	4.80	0.1423	2004	1119.60	94	1149.20	22.00	31.10
APRIL	130.74	7.60	0.5247						
MAY	144.94	10.80	0.5817	2005	1400.80	99	1157.70	22.10	31.10
JUNE	232.54	13.60	0.8253						
JULY	143.56	13.40	0.5761	2006	1038.90	99	1210.80	22.00	31.10
AUGUST	87.16	11.60	0.3440						
SEPTEMBER	257.12	16.20	1.0343	2007	1328.30	107	1275.70	21.70	31.40
OCTOBER	167.72	14.80	0.6370						
NOVEMBER	22.94	3.20	0.0921	2007	1328.30	107	1275.70	21.70	31.40
DECEMBER	9.16	0.40	0.0344						

According to Lujan (2003), hydraulic conductivity, water retention, soil crusting, soil compaction and workability are influenced strongly by the primary particles. He indicated that the Fourier Index can be used to assess the climatic aggressiveness, as follows:

$$F_1 = \frac{1}{P} \sum P_1 \quad (1)$$

where P_1 = monthly precipitation
 P = Annual precipitation

The month of September has the highest Fourier Index of 1.0343 (Table 4) followed by the month of June with 0.8253. The lowest index occurs in the month of December with 0.0344. Thus climatic aggressiveness was at a peak in the month of September while it was lowest in the month of December.

The cumulative effect of rainfall, evaporation, temperature and relative humidity obtained from the five year data (Table 4) favors the establishment of a landfill system.

Leachate evaporation rate is expected to be low because of the small surface area of the site with minimal exposure to wind and temperature. High evaporation during the dry season minimizes leachate formation and infiltration rate. Furthermore as observed by Ekpo et al. (2000), adequate rainfall during the rainy season will enhance waste decomposition.

Soil hydraulics

Bottom leakage potential (L_p): The bottom leakage potential is the potential for passage of leached materials from the base of the landfill through the substrata into the groundwater body. According to Frempong (1998) there is the tendency for precipitation entering the landfill through cover soil to carry deposited waste in suspension since an absolutely impermeable medium does not exist in nature. According to Hagerty and Pavoni (1973):

$$L_p = \frac{300(k)^{1/3}}{tb} \quad (2)$$

where L_p = Bottom leakage potential
 k = permeability in **cm/s**
 tb = bottom soil thickness in **m**

The bottom leakage potential is related to the permeability of the substratum which is confined between the base of the fill and the aquifer. For the study area the bottom leakage potential at the 4.00m depth ranges from 2.71×10^{-3} to 9.26×10^{-3} . According to Hagerty and Pavoni (1973), this range of values is very low and makes the study area suitable for disposal of waste.

Flow Velocity (V_g): Hagerty and Pavoni (1973), proposed a formula to assess the speed with which deleterious leachates can be dispersed in groundwater. This is referred to as the flow velocity V_g .

$$V_g = \frac{S^{1/3}}{\log\left[\frac{1}{k} + 1\right]} \quad (3)$$

where k = permeability in **cm/s**
 S = water table gradient in **m/km**

The calculated flow velocity for the study area ranges between 0.36cm/s and 0.46cm/s. This shows that when leachate reaches the groundwater body they would be distributed within the speed limits of 0.36 – 0.46 cm/s and this range is considered to be low.

CONCLUSIONS

Comprehensive evaluation of the study area using geochemical methods has helped in arriving at the following conclusions:

- The pH range of the soil is a strong indication that they are suitable as landfill for wastes that are rich in heavy metals as most of them will be in insoluble form hence they are unavailable to the environmental media. However the TOC and CEC of the soils need to be enhanced for its suitability as landfill. XRD analysis revealed the main clay mineral in the studied soils to be kaolinite often associated with well drained environment.
- Baseline groundwater chemistry reveals average K, Mg, Ca, Na, and Si concentrations for the community wells to be higher than those for the location wells. The trace elements as well as Cl^- and NO_3^- concentrations in all the water samples were found to be lower than the limits set by both the WHO (2006) and SON (2007). The ground water flow direction was found to be in the North - South direction with hydraulic gradient 17.70 m/km.
- High evaporation during the dry season minimizes leachate formation and infiltration rate. Furthermore adequate rainfall during the rainy season is expected to enhance waste decomposition. The bottom leakage potential range of 0.36cm/s to 0.46cm/s at the 4.00m depth is very low and makes the study area suitable for disposal of waste. Baseline information on soil properties, groundwater chemistry and hydraulics have been established.

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