Characterization of Leachate and Bio-Solids of Municipal Solid Waste (MSW) Dumpsite in Port Harcourt, Nigeria

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Abstract
Characterization of leachate and biosolids of municipal solid waste (MSW) dumpsite in Iwofe area of Port Harcourt was carried out to determine the extent of deleterious materials in the biosolids. The study also investigated the possible contamination of groundwater sources by establishing leachate plume depth with vertical electrical sounding (VES). VES located at the dumpsite with the transverse running normal electrical imaging surveys was conducted along 15 profiles in the site using ABEM SAS1000 resistance meter, two sets of multicore cables, 41 steel 1m length electrodes and ES464 model automatic electrode selector. The survey lasted approximately 1 hour 30 minutes in each location. It also involved the collection of water, leachate and biosolids to determine their chemical composition by means of laboratory analysis. Each waste dump leachate samples were collected and analyzed; the samples were filtered through 0.21m membrane and stored for chemical analysis of pH, electrical conductivity (EC), and soluble ions concentrations of sodium, potassium, calcium and manganese. Pearson product moment correlation (r) was used to investigate the relation between the parameters measured. ANOVA was used to test for significant differences in the concentration of contaminants in the biosolids and leachate samples. Laboratory analysis of the leachate shows presence of heavy metals including Zn (0.912 mg/L), Fe (10.62 mg/L), Cu (0.138 mg/L), Mg (7.25 mg/L), Mn (11.38 mg/L) and Pb (0.00084 mg/L). The concentration of metals in the groundwater samples include Zn (0.022 mg/L), Fe (3.38 mg/L), Cu (0.066 mg/L), Mn (0.003 mg/L), Pb (0.034 mg/L). It was also observed from the vertical electrical sounding that groundwater system in the Iwofe area of Port Harcourt is at risk of pollution due to leachate plume hitting the groundwater system. Samples showed that the municipal solid waste dumpsite in the area has contributed to the pollution of soil and groundwater in the area. Biosolids may not be fit for use on plants without proper treatment.

Keywords: *Leachate, Biosolids, Municipal Solid Waste (MSW), Dumpsite, Port Harcourt*

Introduction

Solid waste management has been a major problem in the world especially in most developing countries (Rahman *et al*., 2013). The disposal of solid waste in borough pits and depressions has led to an unsustainable use of land. Dumping of MSW in pits and open spaces is an age long practice, this method involves dumping waste on a large piece of land and once full, entombing the waste.

However, in this part of the world there are no known engineered landfills. What is common is the dumping of waste in depressions, borough pits and road sides in heaps (Nkwachukwu *et al*., 2010). Wastes are not sorted and it's not uncommon to find household wastes, hospital wastes, industrial and commercial wastes all in the same dump site (Ziraba *et al*., 2016), although, most urban MSW are from industrial, commercial and residential sources, each contributing different types of contaminants to the waste stream.

The main problem associated with dumpsites is the decomposition of these municipal solid wastes which is accompanied by the formation of leachate (Adhikari, 2014) and eventual contamination of groundwater due to its migration. Based on case studies, leachate discharge at sites not properly engineered has been reported by Alslaibi *et al.* (2011) as a main factor in the increase of groundwater contamination. The composition of leachate is varied and consists of a wide range of organic and inorganic pollutants. Experimental works carried out to determine concentrations and distributions of both municipal and industrial waste indicated a considerable presence of heavy metals in soils due to land disposal of waste (Eshiet and Agunwamba, 2012). According to (Emereibeole *et al.*, 2021) Leachates from solid waste disposal facilities are the main pollutants of groundwater resources, as they contain varying concentrations of inorganic and xenobiotic organic pollutants.

Further Studies have shown that soil and groundwater system can be polluted due to poorly designed waste disposal facilities, leakage from underground storage tanks and agricultural wastes. Soil and groundwater acidification and nitrification have been linked to waste dumps (Bacud *et al.*, 1994) as well as microbial contamination of soil and groundwater system (Awomeso *et al.*, 2010). The greatest risk for ground and surface water contamination occurs immediately after land application when soluble organic matter levels are elevated and when preferential flow of biosolids through macropores in soil is most probable or during significant rainfall events (Goss *et al.*, 2013).
Open waste dumpsite leads to organic waste biodegradation which creates a greenhouse gas called landfill gas (LFG), also, water that enters the open dump site forms leachate which is contaminated with various biodegradable and non-biodegradable pollutants. These pollutants can be transported to the surroundings. The solid waste dumped in a dumpsite not only cause nuisance with its offensive odour but also constitute a health hazard and an environmental burden (Öman and Junestedt 2008; Kjeldsen *et al.* 2002). According to (Kjeldsen *et al.*, 2002), the major potential effects of a leachate release to surface water include oxygen depletion in the surface water body and changes in the stream bottom fauna and flora and ammonia toxicity.
Generally, leachate is characterized by high values of COD, pH, ammonia, nitrogen and heavy metals, as well as strong color and bad odour. Also, the characteristics of the leachate may also vary with regard to its composition, volume and biodegradable matter present in the leachate. It is based on these factors that it becomes necessary to characterize the leachate and bio-solids from open waste dump sites in Iwofe area of Port Harcourt to determine their composition and establish if they will differ from the general observation and what factor could account for such difference.

Materials and Methods

The study area is Iwofe road dumpsite, Rumuolumeni community in Port Harcourt metropolis, Rivers State. Geographically, Rumuolumeni is situated between latitude 4˚49'N and longitude 6˚ 58'E, this latitudinal location implies that the study area lies within the tropical region with all its climatic and topographic characteristics. Rumuolumeni is bounded by Mgbuoba on the North, Rumueme on the East, and on the South by other parts of Port Harcourt. The area has an estimated total land mass of 15 km and has a total population of 32,000 (NPC, 2006), which forms part of the entire population of Obio/Akpor Local Government Area in Rivers State. It also houses the Rivers State Government owned Ignatius Ajuru University of Education.
Rumuolumeni as well as other communities in Obio/Akpor Local Government Area are part of the Port Harcourt Metropolis in Rivers State. Port Harcourt Metropolis in the Niger Delta region of Nigeria is the fourth largest urban centre of the country. With an estimated

population of 1,947,000 (Demographia, 2016), it possesses substantial natural resource prominent among which are major oil and gas deposits, a variety of solid minerals, good agricultural land and water resources, a large labour force and a vibrant private sector. The research area in particular is the dumpsite at Iwofe road and its surrounding residential community in Rumuolumeni.

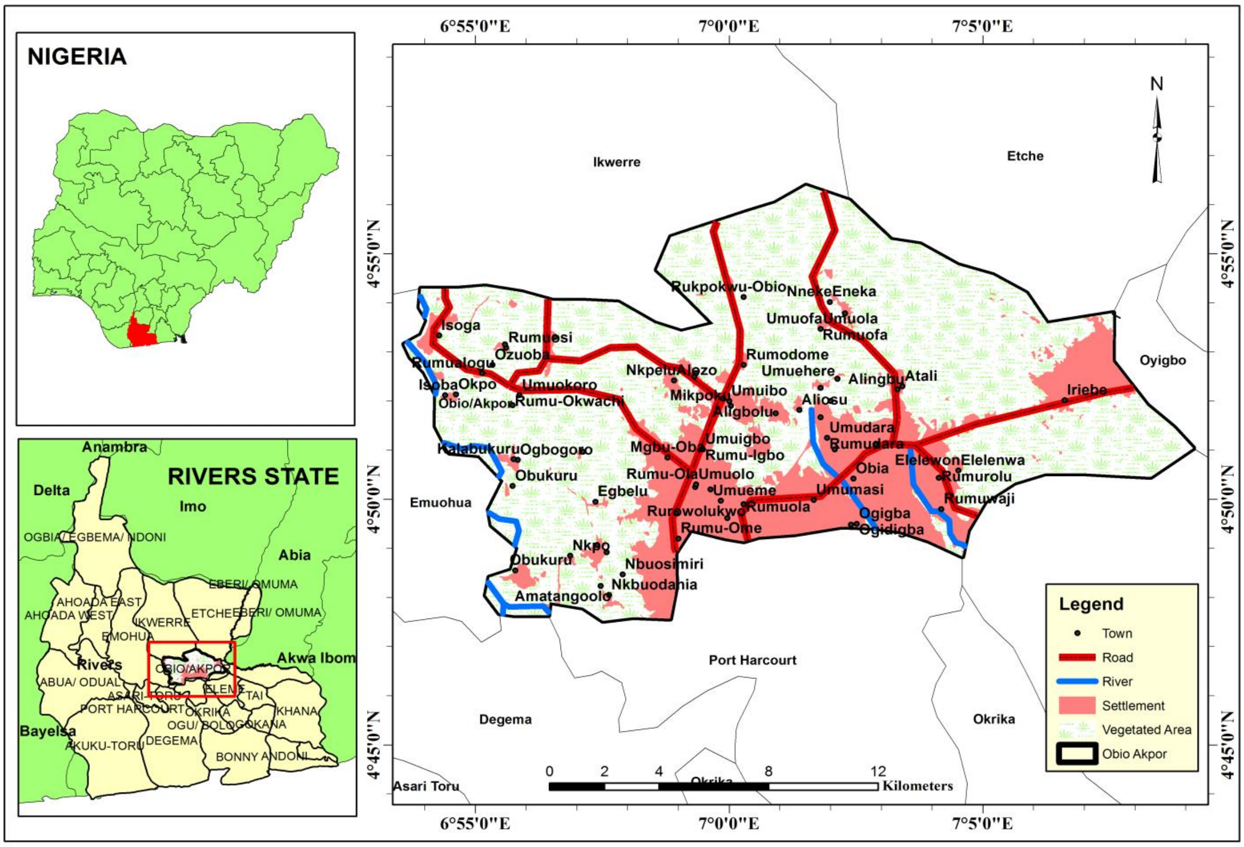

Fig 1: The Study Area (Obio/Akpor Local Government Area Study Area)

Geology of the study area

The study area is located on sedimentary basin of the Southern Part of Nigeria with topography configuration that have evolved from the sedimentary patterns of the last 75,000 years as reported by Allen, sited in Oyegun, (1999). It consists of accumulations of cretaceous and tertiary sediments that are influenced by gravitational instability and tectonic forces (Oyegun, 1999). The general surface feature of the area is very unique. The areas fall within the coastal belt on the sedimentary environment that corresponds lithologically to the Agbada, Akata, and Benin formations from earliest to recent of the modern Niger Delta. The soils in the region are mainly sandy-loams, humus, alluvium and outer belt of salt water swamps, clay and mud. The sands are fine, coarse grained, unconsolidated and granular in texture. The depth to the usable aquifer in the area is approximately 30-45m meaning leachate plum can hit the groundwater before they are effectively filtered.

Instrumentation/Methods of Data Acquisition

OHMEGA-500 Electrical Resistivity Equipment was used to conduct a Vertical Electric Sounding (VES). Electrical resistivity method was chosen in this study because the constituent of inorganic pollutants increases the number of ions in leachate and hence facilitates the current movement in the medium. VES station was located at the dumpsite, with the traverse running normal. Electrical imaging surveys was conducted along 15 profiles in the site using ABEM SAS 1000 resistance meter, 2 sets of multi-core cables, 41 steel 1 m long electrodes and ES464 model automatic electrode selector. The electrodes were connected along the cable at 5 m spacing. The electrode selector chose 4 active electrodes following Schlumberger configuration for each resistance measurement. In this configuration, 2 outer electrodes were used to penetrate the electrical current into the ground and another inner pair of electrodes was used to measure the current potential resulting from the current flow in the ground. The measured resistance was stored in the memory and was retrieved for inverse modeling purposes. The survey lasted approximately 1 hour 30 minutes in each location under favorable weather condition covering a distance of about 160 m. In each traverse all necessary precautions required in geo-electric measurement were duly considered. Transmitter electrodes (A, B) were used to inject current into the ground. The current flow between A and B was measured with the potential electrodes (M, N) (Figure 2).

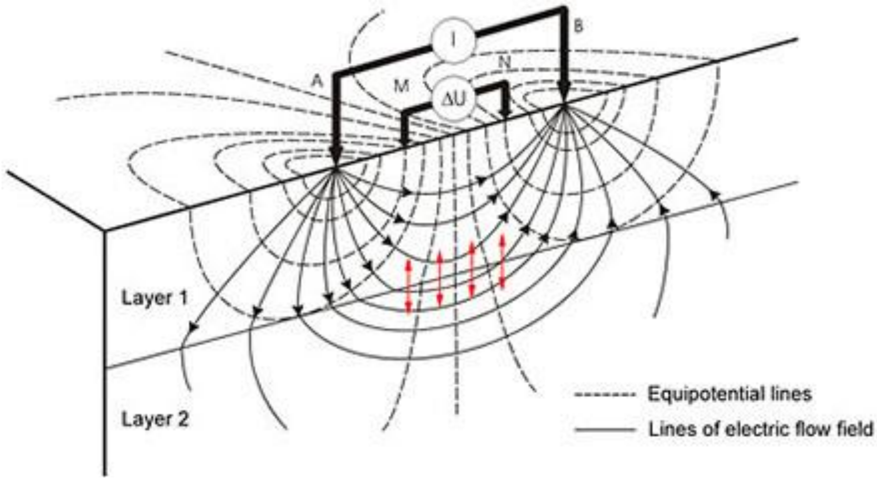

Fig 2 Point-measurement electric flow field

Data Processing

Data generated in the field was subjected to full computer processing techniques, applying the Schlumberger computer automatic analysis package, and the Advanced Geophysics Incorporation (AGI) 1D resistivity analytical software.

$$Apparent\ Resistivity\ (\rho a) = \pi\frac{(AB/2)^2 - (\mathbf{MN}/2)^2 * R}{\mathbf{MN}}\ (Ohm\text{-}m) \quad \ldots\ldots\ldots\ldots\ldots\ldots.(eqn.1)$$

AB/2 = Current Electrode spread, MN/2 = Potential Electrode spread

Thus, Apparent Resistivity Equation (1) can be expressed as follows:

$\rho a = K \times R\ (\Omega\text{-m}),\ (1)$ ……………………….(eqn.2)

Where: K = geometric factor; $\pi\frac{(AB/2)^2 - (\mathbf{MN}/2)^2}{\mathbf{MN}}(m)$ ………………..(eqn.3)

R = field resistance = I/V (Ohms).

I = current passed to the earth through electrodes, and V = voltage

Interpretation of field data

The acquired data obtained was interpreted using 1Pi2win software. The results from the software were then analyzed based on the number of layers, the resistivity, the depth of aquifer contamination and the thickness observed. The result was then compared to the type of resistivity sounding curve observed in the study area in order to delineate area of low and high resistivity values which were then used to identify area of contamination.

Physicochemical Analysis and Characterization of Bio-solids and Leachate

To understand the effect of leachate generated from the waste dumpsite on the environment and the soil in the study area. Bio-solids (soil/sludge) samples and leachate sample were collected and analyzed (Table 1 and 2). Each representative waste dump leachate samples were collected and analyzed during the study period from October 2019 to February 2020. The collected samples were filtered through a 0.21 m membrane and stored for the chemical analysis of pH, EC and soluble ions concentrations of (Na^+, K^+, Ca^+, $Mg^{2+,}$ NO^{-3}, HCO^{-3}, CO_2^{-3} and Cl^-) as well as the concentrations of As, Pb, Cd, Cr, Co, Cu, Fe, Mn, Ni, Zn and V in the landfill. The chemical composition of the studied samples were determined according to Rainwater and Thatcher (1979) for the determination of soluble SO_2^{-4}, (Page *et al.*, 1982) for the determinations of pH, EC and the concentration of soluble (Na^+, K^+,Ca^{2+}, Mg^{2+}, NO^{-3}, HCO^{-3} CO_2^{-3} and Cl^-). The sodium adsorption ratio (SAR) values of the landfill leachates were calculated using the following formula:

$$Sodium\ Adsorption\ Ration\ (\ SAR) = \frac{\mathrm{Na}}{\frac{\sqrt{\mathrm{Ca+Mgc}}}{2}}$$

Where:

Na^+, Ca^{2+} and Mg^{2+} are expressed as meq L_1, as described by Page *et al.*, (1982).

The concentration of $N0^{-3}$ was determined using phenol disulphonic acid, according to Maiti (2004). The chemical oxygen demand COD was determined using Closed Reflux, Colorimetric according to the Standard methods for the examination of water and waste water (APHA, AWWA and WEF, 2005). Heavy metals were measured in samples from the landfill leachate after filtration using ICP-AES instruments (Perkin Elmer, Model 4300 DV). Also, heavy metals were determined in the bio-solids (landfill sediments) after digestion of the sediments.

Care was considered to avoid metal contamination in the process of sampling, extracting and analysis. All equipment and containers were soaked in 10% HNO_3 for 24 hours then rinsed thoroughly in de-ionized water before use. Also, quality control was assured by performing duplicate analyses on all samples and by using reagent blanks and standards. The values of the studying metals below the detection limits of the ICP were rejected.

Table 1 Site Specification for Sampling

Sampling Location	Type
1. Leachate Collecting Point (10 points along the waste dump site)	Leachate
2. Borehole Water (10 samples from both up and down section)	Groundwater
3. Soil/sediment Samples (Along the transect of the waste dumpsite)	Bio-solids

Table 2 Details of Parameters Monitored, Methods of Analysis & Instrument used

Parameters	Method Adopted	Apparatus/instrument
pH	Electrometric method	Electronic pH meter
Electrical Conductivity (EC)	Laboratory method	Delux conductivity meter
Biochemical Oxygen Demand (BOD_5)	Winkler's Method	Air Incubator
Chloride (CT)	Argentometric method	-
Sulphate (SO_4^{2-})	Turbidimetric method	UV-Visible Spectrophotometre (Varian Make, model 50 Bio)
Phosphate (PO_4^{3-})	Colorimetric method	UV-Visible Spectrophotometre (Varian Make, model 50 Bio)
Amonniacal Nitrogen (NH_4^+-N)	Ammonia-selective Electrode method	Expandable Ion Analyzer EA940, Orion Research
Heavy metals- Arsenic (As), Cadmium (cd), Chromium (cr) Mercury (Hg), Lead (Pb), Zinc (Zn) Copper (Cu)	Graphite Furnance Atomic Absorptionmetre, Spectrophometric Elmer) method	Atomic Absorption Spectropho (AAnalyst 400, Pelkin

Data analysis

The data collected was subjected to descriptive statistics that will employ the use of graphical illustrations to present requisite data. Pearson Product Moment Correlation (r) was used to investigate the relations between the parameter measured. One-way analysis of variance (ANOVA) was used to test for significant difference in the concentration of contaminants in the bio-solids and the leachate samples.

Results and Discussion

Table 3: Physicochemical and heavy metal concentration of leachates

S/No	Parameters measured	Units	Site 1	Site 2	Site 3	Site 4	Site 5	Mean conc.
1	Electrical Conductivity	µs/cm	15610	15700	15600	16253	1475	12927.6
2	Total Dissolve Solute	mg/l	10.90	22.00	137	116	66.00	70.38
3	pH	_	5.56	5.22	5.69	5.19	6.00	5.53
4	Turbidity	FAU	340	200	304	203	215	252.4
5	Total Organic Carbon	%	106	108	108	110	101	106.6
6	Chloride	mg/l	1401	1400	1408	1406	1400	1403
7	Nitrate	mg/l	0.04	0.05	0.08	0.05	0.04	0.052
8	Sulphate	mg/l	712	703	764	722	728	725.8
9	Phosphate	mg/l	0.01	0.02	0.02	0.02	0.03	0.02
10	Total Hardness	mg/l	380	380	380	382	380	380.4
11	Iron (Fe)	mg/l	10.67	10.52	10.82	10.54	10.54	10.62
12	Magnesium (Mg)	mg/l	7.32	7.06	7.28	7.28	7.31	7.25
13	Copper (Cu)	mg/l	0.11	0.15	0.17	0.13	0.13	0.138
14	Lead (Pb)	mg/l	0.008	0.008	0.009	0.008	0.009	0.0084
15	Manganese (Mn)	mg/l	11.7	11.2	11.9	11.5	10.59	11.38
16	Zinc (Zn)	mg/l	0.98	0.87	0.98	0.88	0.85	0.912
17	*Total Coliform Count (TCC)*	CFU/100ml	75	75	74	75	75	75

The Physicochemical and heavy metal concentration of leachates are summarized in Table 3. The pH value of leachate samples from the dumpsites show the composition is acidic with mean value of 5.53. The mean concentrations of EC of the five sampling point is 12927.6 µs/cm; for TDS is 70.38mg/l, turbidity 252.4 and TOC 106.6% respectively. The concentrations of major anions in the dumpsites including Cl, NO_3, PO_4 and SO_4 are as presented in the table. The results show that cationic and anionic concentrations are quite high in Iwofe dumpsite. Similar findings and conclusion were reached by Nwankwoala and Offor, (2018) in their study on the contamination assessment of soil and groundwater within and around semi-controlled solid waste dumpsites in Port Harcourt, Nigeria.

Laboratory analysis of the leachate show presence of heavy metals including Zn (0.912 mg/l), Fe (10.62 mg/l), Mg (7.25 mg/l), Mn (11.38 mg/l), Cu (0.138 mg/l), and Pb (0.00084 mg/l).

Table 4: Physicochemical Properties and Heavy metal levels in Borehole water

S/No	Parameters measured	Units	BH1	BH2	BH3	BH4	BH5	Mean Conc.
1	Electrical Conductivity	µs/cm	16.00	42.00	475.00	203.00	94.00	166
2	Total Dissolve Solute	mg/l	11.00	29.00	330.00	142.00	66.00	115.5
3	pH	_	6.02	5.28	4.69	5.11	5.59	5.34
4	Turbidity	FAU	3.00	0	4.00	3.00	5.00	3.00
5	Total Organic Carbon	%	0	0	0.001	0	0	0.0002
6	Chloride	mg/l	7.2	19.3	220.00	94.50	44.00	76.9
7	Nitrate	mg/l	2.00	13.30	68.00	45.30	25.00	30.72
8	Sulphate	mg/l	0	2.00	26.00	2.00	1.00	6.2
9	Phosphate	mg/l	0	5.10	25.00	10.00	15.30	11.08
10	Total Hardness	mg/l	6.60	18.40	210.00	90.50	40.00	73.1
11	Iron (Fe)	mg/l	1.05	1.23	9.56	6.10	1.48	3.88
12	Aluminium (Al)	mg/l	0	0	0	0	0	0
13	Copper (Cu)	mg/l	ND	0.06	0.11	0.09	0.07	0.066
14	Lead (Pb)	mg/l	ND	0.03	0.09	0.04	0.01	0.034
15	Manganese (Mn)	mg/l	ND	ND	0.009	0.005	0.001	0.003
16	Zinc (Zn)	mg/l	ND	0.01	0.06	0.03	0.01	0.022
17	*E.* Coli	CFU/100ml	NIL	NIL	NIL	NIL	NIL	Nil

BH=Borehole

The result of physicochemical Properties and heavy metal levels in Borehole water are summarized in Table 4. The mean Electrical conductivity of the five boreholes sampled for this study is 166 µs/cm and ranged between 16.00 µs/cm to 203 µs/cm between borehole 1 and borehole 5. The wide difference could be as a result of distance from the dumpsite as well as depth of the borehole. Borehole 3-5 show exceptionally high values indicating elevated levels of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and iron cations (ions that carry a positive charge). The increased conductivity may also mean increased salinity making the affected borehole water not very suitable for drinking purposes.

The concentration of metals in the groundwater samples includes iron (Fe) 3.38 mg/l, Copper (Cu) 0.066 mg/l, Lead (Pb) 0.034 mg/l, Manganese (Mn) 0.003 mg/l, and Zinc (Zn) 0.022 mg/l. Iron is slightly above the permissible limit for potable drinking water. Iron can seep through soil or rock that contains iron. This dissolves the iron, causing it to enter the groundwater. Iron can also enter groundwater from the corrosion of some pipes. Acidic (with low pH) can make iron compounds more soluble. MSW contains scrap metals and other metallic waste, all these add to the presence of iron.

Metallic copper is malleable, ductile and a good thermal and electrical conductor. The presence of copper in the MSW could be as a result that copper is used to make electrical wiring, pipes, valves, fittings, coins, cooking utensils and building materials. Copper compounds are used as or in fungicides, algicides, insecticides and wood preservatives and in electroplating, dye manufacture, engraving, lithography, petroleum refining and pyrotechnics. Copper compounds can be added to fertilizers and animal feeds as a nutrient to support plant and animal growth (Landner & Lindestrom, 1999; ATSDR, 2002). Copper compounds are also used as food additives (eg. nutrient and/or colouring agent) (US FDA, 1994) and all these are components and sources of MSW and rainwater can wash them and infiltrate with the copper to the groundwater.

Characterization of Bio-Solids

Table 5: Chemical Composition of Biosolids

S/No	**Parameters measured**	**Units**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Mean conc.**
1	Electrical Conductivity	µs/cm	1470	1390	670	875	1475	
2	pH	_	5.8	5.3	5.9	6.2	6.8	
3	Colour		Grey	Dark grey	Black	Grey	grey	Grey
4	Total Organic Carbon	%	110	128	128	120	114	
5	Chloride	mg/kg	201	400	108	1006	800	
6	Nitrate	mg/kg	0.24	0.35	0.48	0.35	0.44	
7	Sulphate	mg/kg	1.2	7.3	6.4	7.2	2.8	
8	Phosphate	mg/kg	0.61	0.42	0.22	0.22	0.18	
9	Iron (Fe)	mg/kg	5.02	4.08	4.82	5.54	5.04	
10	Magnesium (Mg)	mg/kg	6.32	1.06	1.28	1.28	0.31	
11	Copper (Cu)	mg/kg	0.01	0.15	0.02	0.03	0.03	
12	Lead (Pb)	mg/kg	3.02	2.06	2.41	0.40	0.92	
13	Manganese (Mn)	mg/kg	0.07	0.05	0.19	0.15	1.02	
14	Zinc (Zn)	mg/kg	3.03	5.05	9.01	2.88	4.98	

15	*Bulk Density*	g/cm 3	122	119	120	120	116	
16	*Total Coliform Count (TCC)*	CFU/ 100ml	75	75	74	75	75	75
17	*Porosity*		0.05	0.07	0.02	0.08	0.07	
18	*Soil class*		Humus	Humus	Humus	Humus	Humus	humus

The colour of the MSW dumpsite biosolids is predominantly grey/black apparently as a result of either humus or the presence of ions. Heavy metals are slightly above the FEPA and WHO limits. The physical composition of the biosolids is a mixture of soil, wood shavings and other MSW materials including paper, foodstuffs, and many other biodegradables.

Conclusion

The study involved the collection of water, leachate and biosolids samples to determine by means of laboratory analysis their chemical composition. The study also investigated the possible contamination of groundwater sources by establishing leachate plume depth with vertical electrical sounding in the study area. The aim essentially is to characterize leachate and Bio-Solids of Municipal Solid Waste (MSW) dumpsite in Port Harcourt and determine the extent of deleterious material in the biosolids so that it can be applied to agricultural lands. In recent times, attention has shifted to the beneficial use of biosolids. Land application of biosolids is an economically attractive management strategy, for it contains a high concentration of organic matter, which can ameliorate soil quality.

This option also ensures that major biosolids-borne plant nutrients (i.e., nitrogen. phosphorus, potassium, sulphur, copper, zinc) are recycled. Benefits also extend to reduction in soil erosion, land restoration and enrichment of forestry land. However, a variety of undesired compounds may also be found in biosolids, which could have adverse effects on the environment such as potentially toxic trace elements (PTE) accumulation, transfer of these contaminants through the food chain or potential for surface water/groundwater contamination, among others. Therefore, the benefits from biosolids land application have to be carefully weighed against its potential deleterious effects.

The study showed that there were some elevated presence of copper, iron and zinc in the biosolids as well as in the leachate. These have to be treated before they can be applied to agriculture. It was also observed from the VES that groundwater system in the Iwofe area of Port Harcourt metropolis is at the risk of pollution due to leachate plume hitting the groundwater system. The geology of the area and the soil show a highly porous media. In conclusion, samples showed that the Municipal solid waste dumpsite in the area has contributed to the pollution of soil and groundwater in the area and requires urgent treatment.

Recommendations

1. Based on the findings of this research, it is recommended that any crop planting on biosolids should be done with care.
2. Considering the nature and geology of the study area which is predominantly sandy loam and clay soils, it is also recommended that continuous soil quality monitoring on-site and off-site areas be done at periodic intervals and results published.
3. Government at either the State or the local council level should endeavor to construct an engineered landfill facility to reduce indiscriminate siting of refuse dumps. Sanitation levies can be charged to ensure the workability of the construction.

4. Stakeholders in the environment should emphasize on monitoring of industrial activities and discharge of pollutants in the environment.
5. Finally, further research should be carried out to assess the environmental and health risks posed by the contamination levels observed in the waste dump soils and leachates in the study area.

References

Adhikari, Bikash. (2014). A Review of Factors Affecting the Composition of Municipal Solid Waste Landfill Leachate. International Journal of Engineering Science and Innovative Technology (IJESIT). 3. 273-281.

Alslaibi, Tamer & Mogheir, Yunes & Afifi, Samir. (2011). Assessment of Groundwater Quality Due to Municipal Solid Waste Landfills Leachate. Journal of Environmental Science and Technology. 4. 10.3923/jest.2011.419.436.

APHA-AWWA-WEF (2005) Standard Methods for the Examination of Water and Wastewater. 21st Edition, American Public Health Association, American Water Works Association, Water Environment Federation, Washington DC.

ATSDR (2002) Toxicological profile for copper (draft for public comment). Atlanta, GA, US Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (Subcontract No. ATSDR-205-1999-00024).

Awomeso, J. A., Taiwo,A. M., Gbadebo, A.M., and A. O. Arimoro. (2010). Waste disposal and pollution management in urban areas: A workable remedy for the environment in developing countries. *American Journal of Environmental Sciences* 6(1): 26 – 32

Bacud,L., F. Sioco, and J. Majam (1994). A descriptive study of the water quality of drinking wells around Payatas dumpsite, Unpublished BSc Thesis, University of the Philippines College of Public Health, 12 – 24.

Eshiet, K. I and Agunwamba, J. C (2012). Contaminant Transport from Disposal Sites and Potential Impact on Groundwater. *Journal of Environmental Science and Technology, 5: 306-318*

Goss, M. J., Tubeileh, A., & Goorahoo, D. (2013). A Review of the Use of Organic Amendments and the Risk to Human Health. *Advances in Agronomy*, *120*, 275–379. https://doi.org/10.1016/B978-0-12-407686-0.00005-1

Kjeldsen. P, Barlaz. M, Rooker. A.P, Baun. A, Ledin. A & Christensen. T.H. (2002) Present and long term composition of landfill leachate: A review Critical *Reviews in Environmental Science and Technology* 32(4): 297-336

Landner L, Lindestrom L (1999) Copper in society and in the environment. Vasteras, Swedish Environmental Research Group (MFG) (SCDA S-721 88).

Maiti, S. K. (2004). *Handbook of methods in environmental studies: Vol. 1*. Jaipur: ABD Publishers

Nkwachukwu, Onwughara & Nnorom, Innocent & Charles, Kanno. (2010). Issues of Roadside Disposal Habit of Municipal Solid Waste, Environmental Impacts and Implementation of Sound Management Practices in Developing Country "Nigeria". International Journal of Environmental Science and Development. 409-418. 10.7763/IJESD.2010.V1.79.

National Population Commission (NPC) (2006) Nigeria National Census: Population Distribution by Sex, State, LGAs and Senatorial District: 2006 Census Priority Tables (Vol.3)http://www.population.gov.ng/index.php/publication/140-popn-distri-by-sex-state-jgas-and-senatorial-distr-2006

Nwankwoala HO and Offor SC (2018) Contamination Assessment of Soil and Groundwater within and around Semi-controlled Solid Waste Dumpsites in Port Harcourt, Nigeria. *Journal of Waste Recycling*. Vol.3 No

Omar, H.M (2016) Treatment of Landfill Waste, Leachate and Landfill Gas: Modelling/Simulation and Experimental Studies. A thesis submitted in partial fulfillment of the requirements for the degree in Master of Engineering Science. The University of Western Ontario. Electronic Thesis and Dissertation Repository. 3731. https://ir.lib.uwo.ca/etd/3731

Oyegun CU (1999), Climate, relief and drainage. In: Alagoa, EJ (ed.) The Land and people of Bayelsa State: Central Niger Delta. Onyoma Research Publications, Nembe. p31

Page, A. L., R. H Miller and D. R Keeney (Ed., 1982): *Methods of soil analysis*; 2. Chemical and microbiological properties, 2. Aufl. 1184 S., American Soc. of Agronomy (Publ.), Madison, Wisconsin, USA, gebunden 36 Dollar.

Rahman, A., L. Hossain, A. Rubaiyat, S. A. Mamun, Z. A. Khan, M. Sayem, and M. K. Hossain. 2013. ―SolidWaste Generation, Characteristics and Disposal at Chittagong University Campus, Chittagong, Bangladesh.‖Discovery Science 4 (11): 25–30.

Rainwater, F.H. and L.L. Thatcher, 1979. Methods of collection and analysis of water samples. Geological Survey Water-Supply Paper. No. 1454. Washington.

US FDA (1994) Code of Federal Regulations. Vol. 21. Food and Drugs Part 182, Substances Generally Recognized as Safe, pp. 399–418, and Part 184, Direct Food Substances Affirmed as Generally Regarded as Safe, pp. 418–432. Rockville, MD, US Food and Drug Administration.

Uyo, Chijioke & Emereibeole, Enos & Mgbeahuruike, Leonard & Irene, Egbuawa & Edo, Friday & Nmecha, Michael & Acholonu, Chidinma. (2021). Groundwater Contamination from a Municipal Solid Waste Dumpsite: Case Study of Obosi, Southeastern Nigeria. Nature and Science. I.J.S.N., VOL.12 (2) 2021: 15-22. 15-22.

Ziraba, A.K., Haregu, T.N. & Mberu, B. A review and framework for understanding the potential impact of poor solid waste management on health in developing countries. *Arch Public Health* 74, 55 (2016). https://doi.org/10.1186/s13690-016-0166-4