International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-5, Issue-3, March 2018

Estimation and characterization of municipal solid waste in Nekede landfill, Owerri metropolis, Nigeria.

Okere Kelechi Justin, Abu Gideon O., Ndukwu Benjamin

Abstract— **Municipal Solid Waste (MSW) generation is on the rise in metropolitan areas especially in developing countries such as Nigeria. Poor understanding of waste dynamics, political and fiscal capital has led to inadequate management. Consequently there are plethora of environmental issues including adverse impact on ecosystem services and functions. So understanding the composition and characteristics of generated waste is essential in developing the right policies and strategies for efficient management. MSW generated in Owerri metropolis are hauled commingled to Nekede landfill near Otamiri river. Data on quantity of waste generated are not available. Moreover reports by varying researchers indicate heavy metal contamination of Otamiri river. Thus this research was done to estimate and characterize waste discharged at Nekede landfill. Emphasis is on hazardous component, since when discharged into landfill, it could introduce heavy metals in adjoining rivers. Therefore study will enhance understanding the link between hazardous waste composition and heavy metal contamination detected in Otamiri river. A multi criteria assessment has been applied in this research. They include review of relevant literatures. Reference [4] was used to sample and classify the MSW; the hazardous waste fraction was benched on the classification by [31] and [11]. Result indicate a monthly MSW generation of 19,950-30,000 tonnes with organic portion of over 60%; per capita generation rate of 1.24-1.9kg/day with hazardous waste fraction of between 16.2% and 18.7%. This correlate the studies by some researchers that implicated the Nekede landfill. Yet further studies should analyze the varying components of the hazardous waste and model the mass transport phenomena via conceptual site model (CSM) to confirm the impact of the Nekede landfill on Otamiri river.**

Index Terms— **Owerri metropolis, Waste management, Waste characterization, Nekede landfill**

I. INTRODUCTION

Municipal Solid Waste (MSW) generation worldwide has reached 2 billion tonnes [36]. In Nigeria about 70,000 tonnes is generated daily [41]. Generation statistics of some key cities in Nigeria are elucidated in Table I. Generation has exacerbated due to population explosion and enhanced economic status in metropolitan areas [42], [3]. The waste sources are human dwellings, small and medium enterprises (SMEs) and sometimes from the health care services [3]. Similar to developing countries trend, most waste generated in Owerri metropolis end in open landfill, others burnt or discharged in drains. Reference [50] and [53] highlighted the unsustainable practices in Owerri metropolis. They indicated common practices of burning and landfilling of municipal waste.

Okere Kelechi Justin, PhD Research Fellow, Institute of Natural Resources, Environment and Sustainable Development (INRES), University of Port Harcourt, Nigeria.
Professor Gideon O. Abu, Professor of Microbiology and Board member Institute of Natural Resources, Environment and Sustainable Development (INRES), University of Port Harcourt.
Professor Benjamin Ndukwu Professor of Plant Science & Biotechnology - University of Port Harcourt and Director Institute of Natural Resources, Environment and Sustainable Development (INRES), University of Port Harcourt, Nigeria.

Table I: Waste generation statistics in some major cities in Nigeria

City	Population	Agency	Tonnage/ month	kg/ capita/ day	Ref.
Abuja	159,900	Abuja Environmental Protection Agency	14, 785.00	0.66	[41]
Kaduna	1,458, 900	Kaduna State Environmental Protection Agency	114,443.00	0.58	[41]
Lagos	8,029,200	Lagos State Waste Management Authority	255,556.00	0.63	[41]
Makurdi	249, 000	Urban Development Board	24,242.00	0.48	[41]
Port Harcourt	1,053,900	Rivers State Environmental Management Agency	45,153.18	1.1- 1.25	[39]

Thus adverse implication on air, land, rivers and ecosystem services integrity cannot be over stated. Pollution of surface and groundwater resources is of serious concern especially with the blue economy concept-an oceancentric approach of caring for aqua resources which endows mankind with final frontier for humanity, as well as push for sustainable development, premised on ocean coverage of about 70% of earth surface and home to 50-80% of entire natural resources [14]. So imperative to continually study the integrity of water and associated ecosystems and resources. Geochemical assessment of groundwater sample via boreholes nearby closed Avu landfill and Otamiri river were studied by [19]. Study indicated pollution trend with increase in iron and nitrate from previous study by [45] and implicated the landfill. Building on that, commendable studies on pollution status of Otamiri and Nworie rivers-a major tributary of Otamiri river have been done. Reference [27] and [15] investigation on Otamiri river identified high microbe levels. Reference [30] documented same trend result in Nworie river. The study hinged pollution on dumping of hospital waste. Other interesting studies point to heavy metal contamination of Otamiri river, mostly incriminating waste discharge. Table II summarizes selected works in that line.
The adverse impact from landfill in some western countries has been documented [16]. Hence understanding the waste generated characteristics could enhance potential to develop policies and strategies to mitigate related issues. Waste characterization informs data on amount and type of substance [1], [46]. Besides, [22] acknowledge information

on waste characteristics as key element of municipal waste management system [1] received at dumpsite. But poor compilation in African cities reported [47], [5]. Thus this study aims to quantify and characterize waste landfilled in Owerri metropolis. Emphasis is on hazardous component to understand a link between hazardous waste composition and heavy metal in Otamiri river as detected by earlier researchers and shown in Table II. Since hazardous waste could get discharged into landfills, introducing heavy metals [32]. The introduction and consequences of heavy metals through municipal solid waste cannot be overstated- toxicity of metals beyond certain concentration could be polluting and injurious. For instance according to Sommer *et al.*(1976) as reported by [7], part per billion concentration increase of copper in ocean was adverse on many species of phytoplankton and eggs of some fish. Sampling was at the 4 year old Nekede dumpsite which serves the entire study area and located about 300 metres to Otamiri river. We carried out the study between December 2015 and May, 2016.

Table II: Varying heavy metal detection at Otamiri river near Nekede dumpsite.

Reference	Iron	Lead	Chromium	Copper	Nickel	Zinc	Cadmium
[35]	NA	2.38±0.75	5.38 ±0.72	4.84 ±1.18	3.44 ±0.81	NA	2.12 ±0.97
[28]	7.13 ± 0.44	0.69±0.12	NA	5.04±0.38	1.60±0.11	5.17±0.26	1.65
[20]	NA	0.37-0.47	<0.001	<0.001	2.15-2.35	10.47-11.30	<0.001
[15]	0.45 ±0.09	0.03	NA	0.11	NA	0.92 ±0.35	NA
[26]	0.575	0.125	NA	1.19	NA	0.85	0.056
[37]	0.3-0.58	0.01-0.09	0.01-0.94	0.01-0.25	NA	0.09-0.64	0.00-0.02
WHO/FME 2003 limit (mg/L)	0.1	0.05	0.01	1.0	NA	5.0	0.005

II. STUDY AREA

Waste management issues and municipalities sizes may vary. However Owerri metropolis was chosen because of its metropolitan status. An urbanistic representative [41] located on coordinates 5.485°N 7.035°E on a landmass of 551km^2 and made up of 3 local government areas out of a total of 27 in Imo State- Owerri municipal, Owerri North and Owerri West. It is the administrative, commercial and entertainment capital of Imo State with estimated population of 401,873 (211,298 male and 190,575 female) based on extraordinary Nigeria official gazette of May 15, 2007 for 2006 census [17]. This gives a population density of 729/km^2 which is almost 400% more than present national population density (assumption- at 175,000,000 population and land area of 923,768 km^2). The high density could be attributed to soaring rural-urban migration with consequences that include increased waste generation and pressure on the existing poor and insufficient waste management infrastructure. It is bound by two rivers, Otamiri to the east and Nworie on south. They serve as source of drinking water mainly for the poor especially with public water failure [35], [27].The metropolis is in the tropics and experience two seasons- rainy and dry season during April to October and November to March. Average annual rainfall is 1500- 2200mm with wettest season about June-August [21]. Hence generation of waste with high moisture content as in other tropical countries like Malaysia with similar rainfall pattern where moisture content is about 52.6% - 66.2% [18], [13]. Typical average yearly temperature is 31°C [52], [8], with annual relative humidity of 75% and could be as high as 90% in the rainy season [21]. The stratigraphy of area is consistent with Benin formation with thick, friable sands of insignificant intercalations of sandy clay beds and lenses, hence high hydraulic, transmissivity conductivity and storage coefficient [19], [8]. Fig. 1 shows map designating study area

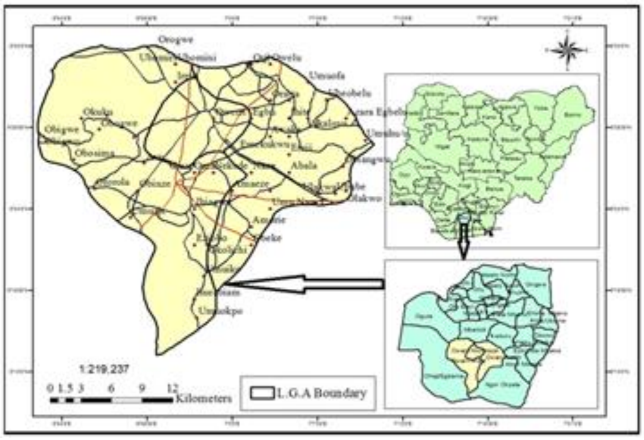

Fig 1: Map of study area.

There are over 120 waste dumping points scattered around the three local government area, but only about 41 points are officially designated transfer dumping points (see Fig 2) where waste receptacle facilities are provided, from where wastes are transferred mainly by government owned trucks to Nekede dumpsite- a burrow pit, near by a dredging strip on Otamiri river less than 300 meters away. From Fig. 2 evidence exist of much pressure on Owerri Municipal area as more than 75% of waste transfer points are domiciled there. Fig 3 showcases all dumpsites in Owerri metropolis. Nekede is the only active dumpsite. Naze (Aba road) dumpsite (less than 250 metres to Otamiri river has been recovered and a not yet in use recreational facility termed Akachi tower built on it. The sources of waste in the metropolis are majorly from households, markets, hotels, schools, hospitals (exclusive of hazardous wastes) and offices. It is noteworthy to state that there are no factories or industries within the metropolis. The prevailing waste management scenario are shown in Fig 4-a, b, c, d. e. f. g and h.

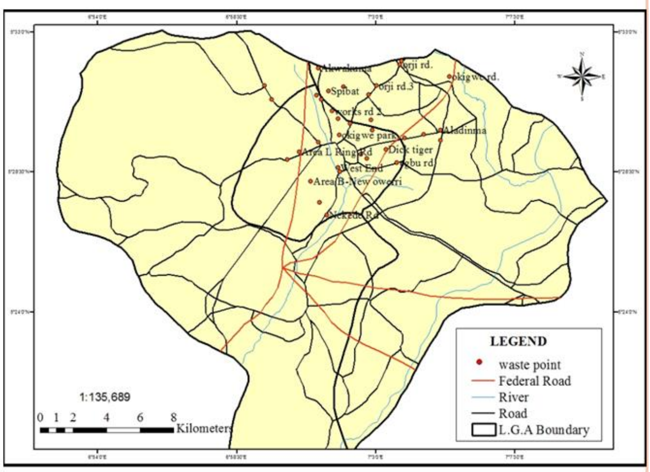

Fig. 2: Waste transfer points in Owerri metropolis.

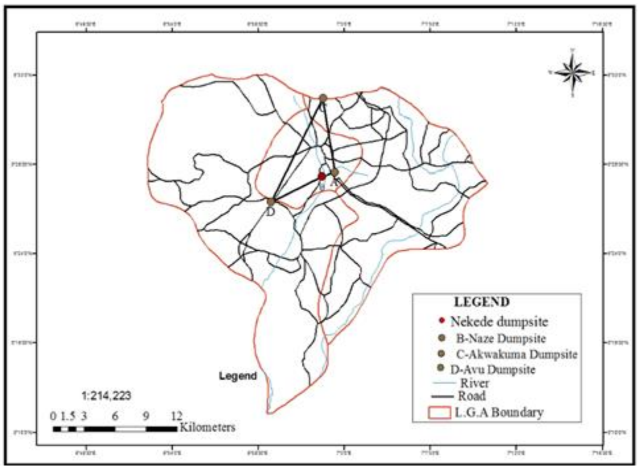

Fig. 3: Landfills in Owerri metropolis.

Fig. 4a

Fig. 4b

Fig. 4c

Fig. 4d

Fig. 4e

Fig. 4f

Fig. 4g

Fig. 4h

Fig. 4a- A cross secion of Nekede landfill with cummingled waste; Fig. 4b- At the dumpsite for sampling; Fig. 4c- with some waste recyclers; Fig. 4d- waste truck loading a roll-on bin; Fig. 4e-plastics/other resources scavenged from waste dumped at Nekede landfill; Fig. 4f- dredging area littered with plastics from dumpsites; Fig. 4g- a truck tipping waste at dumpsite; Fig. 4h- buring waste at Owerri main market at Douglas road.

III. METHODOLOGY

1. Scientific articles, records and documents from existing data bases and other literature concerning solid waste management mostly in developing countries especially Nigeria were identified. We reviewed and critiqued them, hence challenges of waste management highlighted and gaps on existing research identified.
2. Accurate engineering and other technical data and information are virtually deficient or non-existing for disposal services and practices, so assessment could just be prepared from superficial site inspection and verbal site information [5]. So we interviewed key stakeholders, inclusive the Permanent Secretary Imo State Ministry of Petroleum and Environment, the Director Public Health and 2 Deputy Directors in the ministry. In addition Director of waste management in Imo State Environmental Transformation Agency (ENTRACO) and Nekede dumpsite supervisor were interviewed. This enhanced detailed update of information available from 1. To ascertain the level and capacity of integration of some elements of waste management (collection, recycling, disposal and treatment) and issues with waste management, it was necessary to interview Imo Environmental Transformation Commission (ENTRACO) caretakers (ENTRACO monitors and coordinators at major waste collection spots) as well as waste pickers and residents. Onsite assessments of Nekede and Naze landfills were done. All approved waste deposition spots were also assessed. (Note dumpsite and landfill are interchangeably used in this study)

Data estimation

It is important as not all data are available. There is virtually no soft or hard copy data domiciled by the waste management authorities for public consumption. So data estimation imperative. Several methods for data estimation exist but polynomial regression is more in use. Reference [43] and [29] have employed it in varying related estimates. The technique aims to express the linkage between a variable X as a function of available data C and a response Y that search for best fit in curve for the data. Polynomial of m order is as follows:

$$Y = C_0 + C_1X + C_2X^2 + ... + C_mX^m$$

Estimating population increase, we adopted the average annual Nigeria growth rate of 2.47% [12].

Solid waste generation rate

To estimate solid waste generation rate, MSW amounts in the given region should be evaluated [50]. In a study of solid waste generation estimate in Abuja, Nigeria, [1] used sizes of trucks and their disposal frequency to ascertain generation rate. Hence our study has towed similar line. Therefore daily, we recorded the number, sizes and frequency of waste trucks and associated waste disposal machineries, to ascertain waste generation rate. In classifying and estimating MSW and the hazardous waste component, we adapted earlier works as elucidated in Table III and IV respectively. Thereby eight (8) classes of hazardous waste. Imo Environmental Transformation Commission (ENTRACO) is responsible for waste management in Owerri metropolis. For waste collection and transportation, a total of sixteen (16), twenty five (25) tonne and six (6)-fifteen (15) tonne trucks made an average of 209 and 27; 227 and 40 trips to the landfill each week respectively during dry and rainy season.

Sampling, Sorting and Characterization

In sampling and characterization we applied procedure in [4]. Method which may be applied at landfill sites give details of method for collection of representative commingled waste, as well as sorting into different components. It also make clear how number of sorting sample is determined. It is essential in precision and targeted confidence level. General estimation equation for ascertaining number of waste truck for sorting denoted (n):

$n = (t^* s/e \cdot x)^{-2}$,

where t^* = student t statistic at confidence needed confidence level (95%) and s = projected standard deviation, e = desired level of precision and x = projected mean. All values are as in [4]. Random selection of sample trucks ensures quality representative sample of waste stream and reduction of selection bias. There is no weigh bridge at the dumpsite. The waste trucks were directed to the designated discharge point at the landfill and discharged the waste on a clean surface and in one contiguous pile to evade gaps in discharged waste. This is to enhance sample collection. From the waste heap we longitudinally scooped a cross section of the waste upto quantity about 400% of required sample for a truck. Then properly mixed to form a composite sample and a quarter now taken for manual sorting on a flat and clean surface. For obtaining year round data, we sampled in different seasons of the year in the same procedure of random sampling technique mentioned before [34]. Reference [4] recommends 91-136kg for sorting of unprocessed solid waste within 5-7 days. Daily we collected 105 kg of composite waste from each of 9 randomly selected waste trucks. Duration of sampling was two weeks each for rainy and dry season. For weighing, we employed Australian made 10.1 kg- 0.1 g precision XS10001 and 120 kg-20 g precision Toledo 2098 model electronic balance scale.

The mass fraction of component i, *mfi*, is defined and computed as follows:

$mf_i = \frac{wi}{\sum_{i=1}^{n} wi}$, where w_i = weight of component i and j =number of components

Percent of component i, P_i is calculated as below:

$P_i = mf_i \times 100$

The mean component composition for the sampling period is calculated using the component composition results from each of the analysis samples. The mean mass fraction of component i, mf_i, is calculated as follows:

$\overline{mf_i} = 1/n = \sum_{k=1}^{n} (mfi)k$,

and the mean percent of component i, P_i, is thus calculated as follow:

$Pi = 1/n \sum_{k=1}^{n} (Pi)k$.

Where n = number of samples

The waste components have been categorized as in Table III. Constitution of hazardous fraction is elaborated in Table IV

Table III: Description of MSW Components

Class	Description
Mixed paper	Office paper, computer paper, magazines, glossy paper, waxed paper and other paper not in category of newsprint and corrugated
Newsprint/ Corrugated	Newspaper, corrugated medium, boxes or cartons and brown (Kraft) paper and bags
Yard waste	Branches, twigs, leaves, grass and other plant material
Food waste	All food waste but not bone
Wood	Lumber, wood products, pallets and furniture.
Glass	All glass
Ferrous	Iron, steel, tin cans and bi-metal cans.
Hazardous –	All plastics including polyethylene material. Textile, rubber, leather, Aluminum- cans, foil, Personal care & makeup products, Cleaning agents; Pesticides and gardening products, Medicines, Electrical/ electronics, Vehicle maintenance.
Others	Rock, sand, dirt, ceramics, plaster, non-ferrous, non-aluminum metals (copper, brass etc) and bones,

Adapted from [4], [31], [11]

Table IV: Hazardous wastes and associated issues

Category	Example	Hazardous potential	Exposure Pathways
Vehicle maintenance	petrol, brake & transmission fluids automotive oils & cleaning agents, batteries	Toxic, flammable, corrosive	Air, water, waste
Personal care & makeup products	hair dyes, cosmetics, nail polish remover, aerosol, shoe cleaner	flammable, toxic	Usage, waste, water
Home maintenance	Varnish, thinner, paint, adhesives, other solvents	flammable, toxic	Usage, air water
Electrical/ electronics	Cable, CD plates, electrical bulbs and fluorescent tubes, cables	Toxic	Usage, water

Cleaning agents	Bathroom cleaners, furniture polish, liquid stain removers- bleach, oven cleaners, clog removers	flammable, corrosive, toxic	Usage, waste, water
Pesticides and gardening products	rat poison, insecticides, repellant powders, mothballs, disinfectant, wood preservatives	flammable, corrosive, toxic	Usage/ waste
Medicines	pills, syrups, ointments including expired drugs	flammable, corrosive, toxic, reactive	Waste, water
Plastics & others	Plastic rigid, foam, nylon and film, polyethylene, other contaminants	flammable	Waste, water

Source: [31], [11]

Corrosive: can cause burn and destroy living tissues or other materials which come in contact; Explosive: can detonate or explode through exposure to heat, sudden shock, pressure or incompatible chemicals; flammable: can be easily set on fire and Toxic: can cause injury or death through ingestion, inhalation or absorption through skin [31].

Precautionary measure

Accordingly, precautionary measures as documented by [4] are applied. Necessary PPE deployed and equipment included shovels, rakes, push brooms, dust pans, hand brooms, magnets, sorting table, first aid kit, traffic cones, traffic vests, leather gloves, hardhats, safety glasses, and leather boots [4]

IV. RESULTS AND DISCUSSION

Estimation of Municipal Solid Waste Generation rate and Hazardous waste fraction

Owerri metropolis with a 2016 population estimate of 525,596 sent monthly average of between 19,650-30,000 tonnes to Nekede landfill. This figure is small as compared to most of the higher populated major cities like Port Harcourt and Lagos shown in Table I, however the estimated per capita waste generation in Owerri metropolis (1.24-1.90 kg/day) is twice higher than all the cities except for Port Harcourt. Figure is similar with middle income countries [57] and may have been influenced by the relative high level of living. Owerri metropolis has seven (7) higher institutions with several hotels, arguably more than in any other city in the East of the Niger. The waste generation sources, flow pattern and potential externalities are as shown in Fig. 5. It could be seen that rate of generation could be more with some discharges going into drains, bushes and some even burnt. There is an indication that waste to energy (WTE) and Clean Development Mechanism (CDM) could be sustainable ways of utilizing waste generated to avert pollution and climate change.

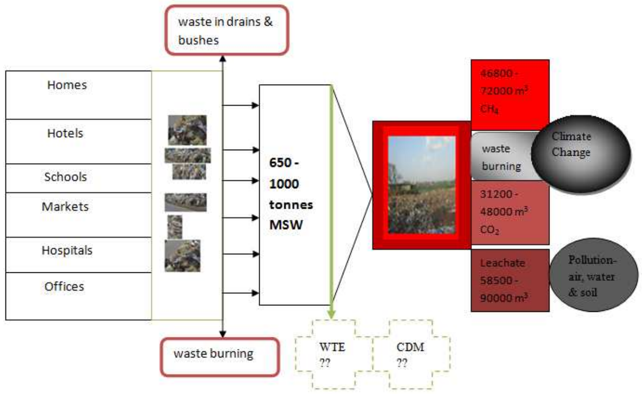

Fig.5: Waste management and potential externalities in Owerri metropolis.

Waste Composition

Table V highlights the waste classification and composition. Food waste composition follow same trend in developing countries. Similar results are documented about organic fraction. While [23] reports 50-75% in Ghana, [34] 78% in Bangladesh and [55] about 63% in Owerri, Nigeria. Population in Owerri according to [55] is domiciled by about 45%, 25% civil/public servants and students respectively, so the high biodegradable waste could be due the social and economic status of the metropolis.

Table V: Waste classification and composition

Rainy season			Dry season	
Class	% Composition		Class	% Composition
Mixed paper	2.1		Mixed paper	3.0
Newsprint/ Corrugated	7.4		Newsprint/ Corrugated	5.3
Yard waste	3.6		Yard waste	6.2
Food waste	60.6		Food waste	56.2
Wood	3.1		Wood	2.3
Glass	3.3		Glass	3.3
Ferrous	2.4		Ferrous	3.7
Hazardous waste	16.2		Hazardous waste	18.7
Others	1.3		Others	1.3

Hazardous waste fraction is high as compared to some previous studies. Study by [11] reported 3.49% in Mexicalli, Mexico and documented other works- Meja, (1999) 0.34% in Mexico; Gendebien *et al*., (2002) - 0.50%, 0.90%, and 0.70% in Switzerland, UK and Hungary respectively. Significant disparity between results and above figures may be due to variation in methodology of research including varying classification of hazardous waste. According to [6] review in 20 countries including US, Canada and some Asian countries like Japan and Pakistan, it showed an average of 0.90±0.39%. But reached 1-4% in places like Canada and Greece, where evaluation was by sampling in landfill, probably after recycling. Moreover [33] reported 5% in England [11]. But since sampling at Nekede landfill was before any form of scavenging, quantity going into landfilling proper could be lower. So with daily waste dumping of 650-1000 tonnes, the government maybe yearly dumping about 38,400-67,320 tonnes of hazardous waste into Nekede waste dumpsite. A dumpsite within 300 metres radius to road, home dwelling and river sources. Meanwhile the heavy metal detection in Otamiri river by several researchers as tabulated in Table II may not be unconnected with the high hazardous composition of MSW. Some samples as noticed during sampling could be thrown out with their content remaining which could have adverse impact as contents could spill out and mix with others, hence generating organic and inorganic compounds during anaerobic decomposition. This may affect solid waste mineralization, the atmosphere, and public health [10]. Moreover could leach into the nearby river, thereby polluting the aquatic ecosystem. Fig. 6 and 7, compares daily sampled MSW and its hazardous component during dry and rainy season. They indicate similar trend in discharge of hazardous waste in landfill, though difference in the average waste generated- rainy season about 16% of waste stream to dry season 18.5%.

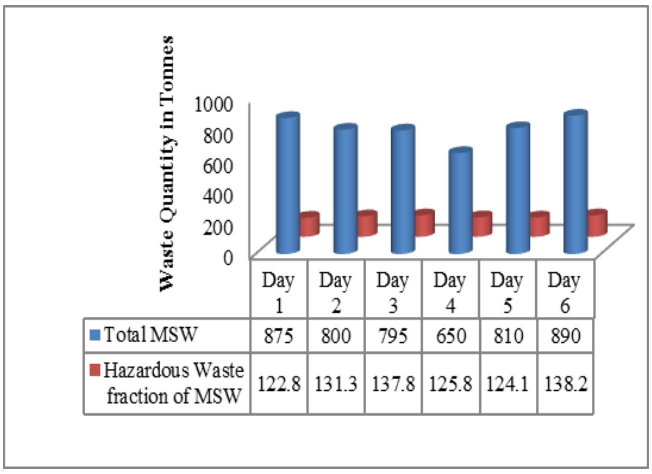

Fig 6: Average daily MSW generation and hazardous waste fraction (May, 2016).

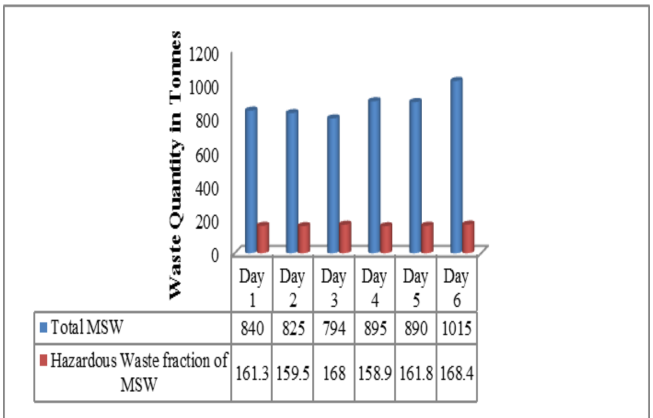

Fig. 7: Average daily MSW mass sampling and hazardous fraction (December 2015) in kg.

This may not be unconnected with the economic recession in Nigeria. From a GDP growth rate of 2.11% in last quarter of 2015, Nigeria's economy dipped to -2.06% at second quarter of 2016 [25]. It has a corresponding effect on waste generation [56] Moreover due to frequent rain and bad state of roads, waste haulage may be hampered, thereby reducing deposition at the landfill, and more waste on streets.

Conclusion and Recommendation

MSW management in Owerri metropolis has been assessed. There is unsustainable management. Entraco is responsible for haulage of waste with coverage mainly in Owerri Municipal council which covers less than 20% of total landmass of Owerri metropolis. Moreover Nekede dumpsite where most of the waste are dumped is just close to a river that is a source of drinking water for the poor living close to the environment. Study found high rate of hazardous waste on the dumpsite, hence could impact on groundwater and nearby surface water-Otamiri. The negative impact of open dumping cannot be overstated. Therefore Government should look the way of integrated system of waste management which requires the political capital to articulate and implement waste management policies that would first consider enlightenment of the populace on issues associated with indiscriminate management of solid waste, encourage 3Rs and energy recovery via engineered landfill. This study suggest further research on the composition and dynamics of the high hazardous waste to ascertain their contamination capacity on the adjoining Otamiri river. Moreover the dredged materials should be tested for integrity as leachate from landfill could impact on the suitability of the dredged resources for construction.

ACKNOWLEDGMENT

We appreciate the Permanent Secretary Imo State Ministry of Petroleum and Environment, the Director Public Health and 2 Deputy Directors in the ministry for divulging vital information. In addition, Director of waste management in Imo State Environmental Transformation Agency (ENTRACO) and Nekede dumpsite supervisor are appreciated for relevant information and site assistance during sampling. Furthermore Imo Environmental Transformation Commission (ENTRACO) caretakers (ENTRACO monitors and coordinators at major waste collection spots) as well as waste pickers and residents around study areas are appreciated.

REFERENCES

[1] B. J. Abur, E. E. Oguche, and G. A. Duvuna, G. A. (2014). "Characterization of municipal solid waste in the federal capital Abuja, Nigeria". Global journal of science frontier research: environment & earth science 14(2). Available: https://globaljournals.org/gjsfr.../1-characterization-of-municipal-solid.pdf

[2] Agamuthu, p. (2011) "leachate studies" manual for SHGD 6172 programme (unpublished), University Malaya

[3] S. M. Ali, A. Pervaiz, B. Afzal, and H. Hamid (2014). "Open dumping and its hazardous impacts on soil and vegetation diversity at waste dumping sites of Islamabad". Journal of king saud university-science, 26, pp.59-65. Available: http://www.sciencedirect.com/science/article/pii/s1018364713000517.

[4] American Society of the International Association for Testing and Materials. (2003). Standard test method for determination of the composition of unprocessed municipal solid waste (d 5231 – 92 (reapproved 2003). Pennsylvania author. Available: www.astm.org

[5] ADB. (2004). "the garbage book: solid waste management in metro Manilla". Available www.adb.org/sites/default/files/publication/29301/garbage-book.pdf

[6] D. Adamcová1, M. D. Vaverková1, B. Stejskal1, and E. Břoušková, (2016). "Household solid waste composition focusing on hazardous

waste". Pol. J. Environ. Stud., 25,(2), pp.487-493.available: www.pjoes.com/pdf/25.2/pol.j.environ.stud.vol.25.no.2.487-493.pdf

[7] S. O. Adefemi and E. E. Awokunmi (2009). "The impact of municipal solid waste disposal in Ado- Ekiti metropolis, Ekiti-state, Nigeria". African journal of environmental science technology, 3 (8), pp.186-189, doi: 10.5897/ajest09.075.

[8] A. N. Amadi, P.I. Olasehinde, E. A Okosun, N. O Okoye, i. A. Okunlola., Y. B. Alkali,., and M. A. Dan-hassan, (2012). "A comparative study on the impact of avu and Ihie dumpsites on soil quality in southeastern nigeria". American journal of 2(1), pp.17-23.

[9] O. M. Amoo, and R. L. Fagbenle, (2013) "renewable municipal solid waste pathways for energy generation and sustainable development in the Nigerian context".International journal of energy and environmental engineering, 4,42.

[10] D. O Buenrostro, S. Ojeda–benitez and B. L. Marquez (2007). "Comparative analysis of hazardous household waste in two Mexican regions".waste management 27: pp.792–801.

[11] S. Ojeda-benitez, A. V. Quetzalli, t. G. Paul and E.C.S. Samantha (2013, December). "Household hazardous wastes as a potential source of pollution: a generation study". Waste management and research 31(12) pp.1279–1284. Available: https://www.ncbi.nlm.nih.gov/pubmed/24293231

[12] Central Intelligence Agency (2014). The orld factbook. Available: https://www.cia.gov/library/publications/the-world-factbook/wfbext/region_afr.html

[13] K. H. Chua, E.J.M. Sahid, and Y. P. Leong, (2011). Sustainable municipal solid waste management and ghg abatement in Malaysia green and energy management 4 pp.1-8.

[14] M. F. Davidson,. (2015, September 22). "Oceans are for everyone". United Nations university. Available: https://unu.edu/publications/articles/oceans- are-for-everyone.html.

[15] M. K. C Duru, K. E. Nwanekwu, E. A. Adindu,., & P. C Odika,. (2012). "heavy metal and bioload levels of Otamiri river, Owerri, Imo state", Nigeria. Archives of applied science research, 4(2) pp.1002-1006.

[16] P. Elliot, D.Briggs, S.Morris, C. De hoogh, C. Hurt, T. K Jensen,.,.... L.Jarup, (2001, August) "Risk of adverse birth outcomes in populations living near landfill sites". British medical journal 323, 363-368. Available: https://www.bmj.com/content/323/7309/363.

[17] NPC "Extraordinary federal republic of nigeria official gazette". (2007). 91(212007), pp.175-198.

[18] M. N.Hassan, T.l. Chong, M. Rahman, M. N. Salleh, Z. Zakaria and M. Awang, (2001). "Solid waste management in southeast asian countries with special attention to malaysia" [proc. 8th int'l waste management and landfill symposium, Italy].

[19] K. M Ibe., & J. C Njoku. (1999). "migration of contaminants in groundwater at a landfill site Nigeria". Journal of environmental hydrology, 7, 8.

[20] G. N. Iwuoha. L.C Osuji,. And M. Horsfall, Jnr. "Assessment of pre-dredging levels of heavy metal pollution in sediments of Otamiri river, Imo state of Nigeria". Research journal of chemical sciences, 2012, 2(6) pp. 82-87.

[21] Imo State government (2016). "About Imo State". Available: www.imostate.gov.ng.

[22] G. F. Lee. &. A. Jones-lee".(1994, May). "Impact of municipal and industrial non-hazardous waste landfills on public health and the environment: an overview available: http://www.gfredlee.com/landfills/cal_risk.pdf.

[23] K.Miezah, K. Obiri-danso, B. Fei-baffoe, and M. Y Mensa. (2015, December). "Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana". Waste management, pp.15-27 available: http://dx.doi.org/10.1016.

[24] A. A. Olukemi, "assessment of environmental problems and methods of waste management in Ado-Ekiti, Nigeria". African research review, 2010, 4(3) pp. 331-343.

[25] National Bureau of Statistics. Nigerian gross domestic product report q2 2016. Retrieved from www.nigerianstat.gov.ng/report/434

[26] J.O. Nwagbara, S. I Ibeneme, E. E. Dim, U. K. Iroegbu, A. O. Selemo, B. C. Ejiogu, and S. O. Onyekuru. "Hydrogeochemical analysis of water samples from Nworie river, Owerri Southeastern Nigeria". The international journal of engineering and science (ijes), 2013, 2 (9), pp.58-67. Available: http://www.theijes.com/papers/v2-i9/part.2/i0292058067.pdf.

[27] F. C. Nwanebu, j. N. Ogbulie, R. K. Obi, and O. A. Ojiako. (2011, august). “Chemical and silt-induced eutrophication syndrome at Otamiri river, owerri, Nigeria”. Journal of public health and epidemiology [online]3(8), pp.358-361. Available: http://www.academicjournals.org/jphe .

[28] D. H. Ogbuagu and C. B. Samuel. "Accumulation and recovery capacity of heavy metals in sand mine ponds of the Otamiri river in Owerri, Nigeria". Interdisciplinary journal of applied science (2013) doi:10.4136/1980-993x. Available: http://www.ambiagua.net/seer/index.php/ambi-agua/index.

[29] K. J. Okere. "University of malaya's low carbon approach: evaluation of CDM potential".(2013). (master’s thesis, university of Malaya, Malaysia) available: http://studentsrepo.um.edu.my/4387/.

[30] C. C. Okore, O. N. Mbanefo, B. C., Onyekwere, S. M., Onyewenjo, A. U Ozurumba, l. U Nwaehiri, and F. Nwagwu, (2014, April) "impact of disposal of hospital waste into nworie river in Imo State Nigeria". International journal of environmental monitoring and protection 2014; 1(1): 7-11. Available: http://www.openscienceonline.com/journal/ijemp.

[31] Rim-Rukeh, a. (2016, January)."Composition and characterization of household hazardous wastes (hhw) in Woji community, Port Harcourt Nigeria". International journal of environmental science and toxicology, 4 (1), pp.146-153. Available: http://internationalscholarsjournals.org/download.php?id=387787418528154798.pdf&type=application/pdf&op=1.

[32] R. J. Slack, m. Bonin, J. R. Gronow, A. And N. Voulvoulis, n. (2005, January). "Household hazardous waste in municipal landfills: contaminants in leachate". Science of the total environment 337, 119-137. Available: https://www.sciencedirect.com/science/article/pii/s0048969704005017.

[33] R. J. Slack, M. Bonin, j. R. Gronow, A. Van Santen, and N. Voulvoulis, N. (2007, April). "Household hazardous waste data for the Uk by direct sampling". Environmental science & technology, 41, pp.2566–2571. Available: https://www.ncbi.nlm.nih.gov/pubmed/17438817.

[34] M.d.Salequzzaman, U. T. Sultana and M. D. A.hoque (2006). "Ecological footprint of waste generation: a sustainable tool for solid waste management of khulna city corporation of bangladesh". Available http://www.necsi.edu/events/iccs6/viewabstract.php?id=362

[35] A. E. Temitope, l. A., Ebeniro, A. G. Oyediran, and T. J. C-Oluwatosin,. (2016). "An assessment of some heavy metals in sediment of Otamiri river, Imo state, South-Eastern Nigeria "Open access library journal, 3: e2462. Http://dx.doi.org/10.4236/oalib.1102462.

[36] UNEP (2015). "Global waste management outlook". Available:http://www.unep.org/ietc/portals/136/publications/waste%20management/gwmo%20report/gwmo%20full%20report.pdf isbn: 978-92-807-3479-9.

[37] J. U. Udensi, H.C. Nwigwe, R.N, Okechi, C.E., Ihejirika, c.f., Johnson, a. A. Nwachukwu,. & H.U. Anuforo (2014, October). "Heavy metals concentration dynamics following the dredging of Nworie river in Imo State, South- Eastern Nigeria". International journal pharmaceutical and medical research, (2), 5. Available: www.woarjournals.org/ijpmr.

[38] E. C Ukpong, E. A., Udo, & I. C. Umoh (2015, march). "Characterization of materials from aba dumpsites". International journal of engineering and applied sciences, 6, 3. Available: www.eaas-journal.org.

[39] A. H., Igoni M. J., Ayotamuno, S.O.T.A, Ogaji, S. D. Robert, (2007, June) "Municipal solid-waste in Port Harcourt, Nigeria". Appl. Energy 84, 664-670. Available: https://www.sciencedirect.com/science/article/pii/s0306261906001644.

[40] R. B. Timiebi & E. Anthony (2017, October)"he state of solid waste management in Port Harcourt city Nigeria" American journal of civil engineering and architecture, 5(4) pp. 160-166 available: http://pubs.sciepub.com/ajcea/5/4/4.

[41] T. Ch. Ogwueleka (2009, May). "Municipal solid waste characteristics and management in Nigeria". Iran journal of environmental health, science and engineering, 6(3), pp. 173-180. Available: http://www.bioline.org.br/pdf?se09026.

[42] G.S.R. Karishnamurti & R. Naidu, (2003, April). "Solid-solution equilibria of cadmium in soils". Geoderma 113, pp.17–30. Available: https://www.sciencedirect.com/science/article/pii/s0016706102003130.

[43] M. Shekarchian, M., Moghavvemi, Mahlia, T.M.I., A. Mazandarani, (2011, August) "a review on the pattern of electricity generation and emission in Malaysia from 1976 to 2008" Renewable and sustainable energy reviews 6(15) pp. 2629–2642.

[44] M. Macias-Corral, Z. Samani, A. Hanson, G. Smith, P. Funk, H.yu and J. Longworth (2008). "Anaerobic digestion of municipal solid waste and agricultural waste and the effect of co-digestion with dairy cow manure" bioresource technology 99 pp. 8288-8293.
[45] K. O. Umah, , "Water resources potentials of Owerri and its environs, (unpublished. M.Sc. Thesis). University of Nigeria, Nsukka, Nigeria.
[46] V. Gawaikar and V. P. Deshpande, (2006, March) "Source specific quantification and characterization of municipal solid waste a review" available: http://www.seas.columbia.edu/earth/wtert/sofos/gawaikar_source%20specific%20quantification%20and%20characterization%20of%20msw.pdf
[47] I. N. Mbue, D. Bitondo, and R. A Balgah. (2015, October) "Municipal solid waste generation, composition, and management in the Douala municipality, Cameroon". Journal of environment and waste management 2(4), pp. 91-101, available: www.premierpublishers.org, issn: 1936-8798x
[48] M. K. C. Duru, E. A. Adindu, P. C. Odika, B. Amadi, C-er okazi, (2012, June),"consequences of long-term consumption of water from nworie river (owerri, Nigeria) on haematological, hepatic, and renal functions using rat model. 24 (1) pp.52 – 57. Biokemistri. Available: https://www.ajol.info/index.php/biokem/article/view/88721/78311
[49] P. Parke, (2016, June, 1) "dirtied by success? Nigeria is home to city with worst pm_{10} levels" available: https://edition.cnn.com/2016/05/31/africa/nigeria-cities-pollution/index.html
[50] C. Anunonwu, A. Amadi, B. Nwankwo, J. Nnadozie, N. Oguejofor, K. Nwoga et al. (2009)evaluation of environmental sanitation in owerri municipal council imo state. Research journal of medical sciences. 2009; 3: 137-140. Available: https://www.cabdirect.org/cabdirect/abstract/20093201044
[51] C. Banks (2009). Optimising anaerobic digestion available: http://www.forestry.gov.uk/pdf/rrps_ad250309_optimising_anaerobic_digestion.pdf/$file/rrps_ad250309_optimising_anaerobic_digestion.pdf on september 4, 2012
[52] H. I. Ezeigbo. Towards efficient water resources management in Nigeria. Water resources, 1990, 2(1): 40 – 42.
[53] G. C. Nwankuo, C. O. Abanobi, J. U. Abaraogu, C. H. Uwalaka, I. C. Chekube and P. Nwankpa (2014, November) hospital waste generation and management practices in Owerri, Nigeria. African journal of environmental science and technology. 8(11), pp. 623-632. Available: http://www.academicjournals.org/journal/ajest/article-full-text-pdf/bd1c07348759
[54] H. K. Ozcan, S. Y. Guvenc, l. Guvenc and G. Demir (2016, october) "municipal solid waste characterization according to different income levels: a case" sustainability 8, 1044; doi:10.3390/su8101044 available: doi:10.3390/su8101044 www.mdpi.com/journal/sustainability
[55] F.E. Uwakwe (2013, July) solid waste management in Owerri municipality and its immediate environs academic journal of interdisciplinary studies 2 no 5 available: http://www.mcser.org/journal/index.php/ajis/article/viewfile/604/626
[56] D. H. F. Liu and B. G. Lipak (1999, December). Hazardous and solid waste. Crc press: miami
[57] K. Kawai and T.tasaki (2016, February) revisiting estimates of municipal solid waste generation per capita and their reliability. J. Mater cycles waste manag 18. 1-13. Available: http://link.springer.com/content/pdf/10.1007%2fs10163-015-0355-1.pdf

Okere Kelechi Justin, PhD Research Fellow, Institute of Natural Resources, Environment and Sustainable Development (INRES), University of Port Harcourt, Nigeria and Ag. Dean Faculty of Natural and Applied Sciences, Hezekiah University, Ishiala Umudi, Nkwerre, Imo State, Nigeria.

Professor Gideon O. Abu, Professor of Microbiology and Board member Institute of Natural Resources, Environment and Sustainable Development (INRES), University of Port Harcourt.

Professor Benjamin Ndukwu Professor of Plant Science & Biotechnology - University of Port Harcourt and Director Institute of Natural Resources, Environment and Sustainable Development (INRES), University of Port Harcourt, Nigeria.