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Landfill Emissions and their Urban Planning and Environmental Health Implications in Port Harcourt, South-South Nigeria

Emissões de aterros sanitários e suas implicações de planejamento urbano e saúde ambiental em Port Harcourt, Sul da Nigéria

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ABSTRACT: This study aimed to provide a perspective on landfill gas emissions, environmental health effects of the urban waste management system in Port Harcourt, Nigeria, and the city's potential for power generation using landfill waste. Real time air quality measurement techniques, field observations and LFG modelling were applied to Port Harcourt city landfills. These disposal areas receive, per year, up to one million tons of domestic and hazardous waste, and produce around 68 million m3/year of LFG (biogas). Additionally, if properly harnessed, this waste may generate more than 11 million KWh /year of electricity. It was also discovered that SO2 emissions from the landfill sites were above the USEPA limits (75ppb), while other regulated gases were within acceptable limits. Particulate matter was mostly above acceptable limits and tended to increase up to 250m radius from landfill sites. Thus, this excess poses serious respiratory and cardiovascular health dangers to the public, especially among inhabitants and workers who operate within 250 metres of the landfills. With this in mind, the following are recommended: a) the outright closure of two of the landfills in the city; b) acquisition of all property within 300 metres radius from the centre of the landfills which is within the "planning area" of each landfill and adequately compensating for all property so acquired; and c) construction of four properly engineered landfills with full capacity to capture leachate and convert LFG into power, through public-private partnerships.

Keywords: landfills; urban waste management; biogas production; particulate matter; landfill gases; Nigeria.

RESUMO: Este estudo teve como objetivo fornecer uma perspectiva sobre as emissões de gases de aterro e os efeitos ambientais do sistema de gestão de resíduos urbanos na cidade de Port Harcourt, na Nigéria, e seu potencial de geração de energia. Técnicas de medição da qualidade do ar em tempo real, observações de campo e modelagem de LFG foram aplicadas aos aterros da cidade de Port Harcourt, que recebem uma mistura de resíduos domésticos e perigosos de até um milhão de toneladas por ano e produzem cerca de 68 milhões de m3/ano de biogás que, adequadamente aproveitado, pode gerar mais de 11 milhões de KWh/ano de eletricidade. Também foi descoberto que as emissões de SO2 dos aterros estavam acima dos limites da USEPA (75ppb), enquanto outros gases regulamentados estavam dentro de limites aceitáveis. As partículas estavam acima dos limites aceitáveis e tendiam a aumentar até 250m de raio dos aterros, colocando sérios riscos para a saúde respiratória e cardiovascular, especialmente entre os habitantes e trabalhadores que operam a menos de 250 metros dos aterros sanitários. Com isso em mente, recomenda-se o seguinte: a) o encerramento definitivo de dois dos aterros na cidade; b) aquisição de todos os bens a menos de 300 metros do raio do centro dos aterros que estão dentro da "área de planejamento" de cada aterro e compensando adequadamente todas as propriedades assim adquiridas; e c) construção de quatro aterros devidamente projetados com capacidade total para capturar lixiviação e converter LFG em energia, através de parcerias público-privadas.

Palavras-chave: aterros; gerenciamento de resíduos urbanos; produção de biogás; material particulado; gases de aterro; Nigéria.

1. Introduction

The concentration of man, materials and infrastructures in urban areas has created a key urban liveability challenge; the issue of managing the wastes generated from human activities and interactions. These wastes, which generally include farmyard products and biodegradables, radioactive, toxic and infectious materials derived from both industrial and domestic sources, are usually dumped in open landfills. Furthermore, these actions occur especially in developing countries without considering their impacts on *public health, especially among inhabitants and workers who operate around the ambience of the landfills.* Municipal open dumping of solid wastes has been described (Rushbrook, 2001; Seadon, 2010; Abd El-Salam & Abu-Zuid, 2015) "as a primitive stage of waste disposal", common around the world in both developed and developing countries. Open dumping of solid waste is a major public health concern and a source of environmental degradation in Nigeria and other third world countries.

Some of the public health concerns are direct emission effects of sulphur and carbon oxides, and methane (and non-methane organic compounds). These gases may be air pollutants and green house gases derived from the natural degradation of organic matter or the burning of landfill wastes, which is a situation commonly encountered in third world countries such as Nigeria. Other key challenges of open waste dumping are: a) scavenging by animals or men; b) proliferation of disease-carrying flies and rodents; and c) aesthetic and odour concerns, which causes general nuisance and reduction in property values. Also, the process of solid waste decomposition produces public health risks, including leachate and gases. These products of decomposition may cause fire, explosion hazards, strong odour, and pollution problems in the air and surface/groundwater (Uwakwe, 2012; Abd El-Salam & Abu-Zuid, 2015).

In the United States of America, there are minimum standards for the establishment of landfills, which are supported by law and enforceable regulations. Also, Municipal solid waste (MSW) or garbage landfills use plastic liners (synthetic) to isolate the trash from the environment. These types of landfills receive domestic garbage (excluding batteries, paints, motor oil, cleaners, chemicals and pesticides) and are regulated by state and local laws. Incidentally, this is not the case in Nigeria, where there are no minimum standards for the construction and management of landfills. Therefore, all manner of unsorted wastes are deposited in municipal solid waste landfills, including industrial and hazardous wastes. This type of landfills has been referred to as 'co-disposal landfills' (Robertson & Dunbar, 2005). Although, co-disposal landfills receive unsorted waste containing garbage (MSW), toxic and/or hazardous wastes, the MSW fraction is the most significant quantity both volumetrically and on a weight basis. Furthermore, the MSW typically generate higher concentrations of non-methane organic compounds (NMOC) vapour comparative to well managed landfills (Robertson & Dunbar, 2005; Pleissner, 2016).

Although landfills obviously generate odour problems, the major health and safety challenge from open dumpsites may be the emission of dangerous but odourless gases, such as methane and carbon dioxide (CO_2). These gases, together with trace amounts of volatile organic compounds (VOC), form what is commonly referred to as landfill gas (LFG). The VOCs consist of toxic air pollutants such as benzene, toluene, ethylbenzene and xylene. These 'invisible' gases are also accompanied by visible emissions of dust and airborne particulate matter (PM_{10}). PM_{10} is found in the exhaust fumes of the trucks that transport waste to the landfill, and leachate away from the landfill. Dust and PM_{10} emissions are also generated from the movement of trucks, and other vehicles that travel on the unpaved access roads to most landfills (uMoya-Nilu, 2007).

Landfill gases (LFG) are also produced by the bacterial degradation of garbage and may consist of up to 60% carbon dioxide, 50% methane (CH_4), small quantities of volatile organic compounds (VOC), and other hazardous air pollutants (HAPs). LFG may also contain minute quantities of hydrogen sulphide (H_2S), ammonia, oxygen (O_2), carbon monoxide (CO) and nitrogen (N_2) from air infiltration, and persistent bio-accumulative toxic compounds. These compounds consist of mercury (Hg) and Non-methane organic compounds (NMOCs) including trichloroethylene, benzene and vinyl chloride. Gas production in landfills begins within a year of waste dumping and may continue for up to50 years, even after the closure of the landfill. Maximum LFG production ranges from < 0.2 to >0.5 m^3 per kg of solid waste. Yet, the determination of the gas production rates, generally depend on: a) refuse composition, climate, time (since emplacement); b) nutrient composition and moisture content of the garbage in place; and c) particle size, compaction and buffering capacity. The LFG production rates reported may vary from 0.0007 to 0.0080 m^3 per kg-yr (Robertson & Dunbar, 2005; Zdeb & Lebiocka, 2016).

Waste generation is increasing in complexity and quantity all over the world, with increasing urbanization, industrialization and population. Gupta *et al.* (2015) reported similar situations in towns and cities from India. According to Ayedun *et al*. (2011), waste generation in Nigeria is increasing both in quantity and in complexity, with biodegradables accounting for around 50%. An estimated annual increment in waste generation is within 0.5 to 0.7%, while current empirical figures range between 0.4 and 0.8 tons /capital /annum. This figure amounts to an annual average of approximately 50 million tons per annum of waste burden, while management capacity is less than 10%. This low waste management capacity has suffered complications due to the "increased inefficiency in waste disposal", hence domestic biodegradable wastes (paper, plastics, rags, and food materials) are openly dumped and burnt in co-disposal landfills.

These dumping occur mostly in unsafe distances from city residential quarters and unapproved dumpsites, thereby creating well-being challenges to city dwellers. Furthermore, this situation affects especially those living close landfills due to the potentials for leachate and emissions from waste decomposition and burning process. Thus, these three processes cause " water, food sources, land, air and vegetation" pollution, culminating in posing substantial risks to public health, environmental degradation and destruction of the ecosystem (UNEP, 2007; Pleissner, 2016).

These environmental and human health risks associated with poor waste management practices have generated "increasing global concern". World Health Organization (WHO) estimates show that about one quarter of the disease burden borne by the world, currently, results from "prolonged exposure to environmental pollution". Additionally, improper management of solid waste is one of the main causes of environmental pollution and degradation in many cities, especially in developing countries (UNEP, 2007). In spite of these serious implications, there are no specific guidelines or policy directives on the best management practices for urban waste in Nigeria. This lack also causes an absence of institutional and legal frameworks for appropriate location and management of dumpsites in a sustainable manner. Moreover, the incentives offered by the conversion of waste to energy, which would have been a part of a sustainable solid waste and environmental management strategy, are not pursued.

This study, therefore, examines the level of emissions from dumpsites in the city of Port Harcourt Nigeria, and their potential environmental health impacts vis-a-vis their proximity to business and living quarters. Furthermore, this study aims to propose a Locational appropriateness, considering whether a dumpsite should be rehabilitated, closed or even upgraded, thus, operating as a source of alternative energy.

2. Study area

Port Harcourt city is considered the capital of the oil industry in Nigeria and also the political capital of Rivers State. It was established in 1913, and today has an estimated population of over 1.3 million people based on the figures from the 2006 census, which put the population of the Port Harcourt metropolitan area at 1,005, 904 persons with a 5.8% annual growth rate.

The study area thus covers an area of over 700 km^2, including the traditional Port Harcourt city area, Obio-Akpor Local Government and parts of Ikwerre, Oyigbo and Eleme Local Government areas. This includes the area within lat 4° 56´ 48.38´´ and 4° 43´ 59.92´´ N, longitude 6° 57´ 30.66´´ and 7° 08´ 00´´ E. Port Harcourt is located within the tropical humid region of southern Nigeria, and is situated on a relatively firm and flat land of about 3.3 – 15 m above sea level and about 66 km from the Atlantic Ocean. Due to increasing rate of urbanization and industrialization, the city has sprawled into hitherto hinterland areas, increasing its size by almost 60% within 20 years (between 1986 and 2007).

FIGURE 1 – Location of Port Harcourt in Rivers State, Nigeria.
SOURCE: modified from Odeh (2012).

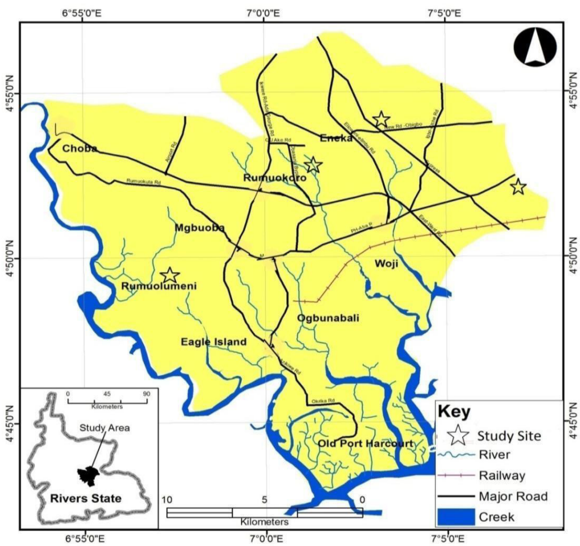

FIGURE 2 – Location of study sites in Port Harcourt.
SOURCE: Adapted from Google (2016).

1986 and 2007). This flat landscape comprises of Coastal plain sands and Niger Delta Recents are traversed by a labyrinth of swamps, creeks and waterways (Mmom & Fred-Nwagwu, 2013). The climate of the area could be described as Equatorial subtropical, which is characterized by heavy rainfall (> 2,500mm) well spread all through the year. However, this rains occur with lower frequency and intensity in the months of august and between December and March of each year; high temperatures (>26ºc) and high relative humidity (>67%) occur all year round.

2.1. Dump sites

The landfill planning area is designated, in this study, as areas lying within 250 metres from the edges of the landfills. This selection was made considering the World Bank's Terms of Reference documents for the sitting of landfills (Cointreau, 2004). These selected areas have been marked with four red lines in the Figures (3-6), showing the location and ambience of the landfills in Port Harcourt on recent Google Earth satellite images (See Figures 3-6).

There are four government officially designated landfill sites in the Port Harcourt metropolis located at Eneka-Igwuruta road, Oyigbo, Eliozo--Eligbolo and Rumuolumeni. These landfills are co-disposal in nature and are generally non-engineered landfills. Additionally, these areas are simply open dumpsite where all manner of unsorted wastes including domestic, biodegradable, non-biodegradable and hazardous wastes are freely dumped into borrow-pits, and burnt periodically to reduce volume. Leachate are also not collected or treated, but allowed to sink into the ground or channelled into nearby wetlands such as the case of the Eliozo landfill (Figure 5).

It is important to highlight that these dumping and burning waste mismanagement operations generate all manners of pollution, including noise from the movement/running of trucks and earth-moving machinery. Furthermore, poisonous gases from waste burning, decomposition, particulate matter that occur from machinery movement and wind detachment, may also be expelled by the trucks and earth-moving machinery. This has made life unbearable for people and businesses operating within the vicinity of landfills. Moreover, is important to notice that this landfill site was not in the initial plan for the development of these areas; these spaces were not earmarked for dumpsites, hence, dumpsites now exist side by side with residential and business housing.

The Obigbo landfill is located within latitudes 4° 52’ 41.268” and 4° 52’ 30.39”, and Longitudes 7° 07’ 26.695” and 7° 07’ 45” along the Aba-Port Harcourt Expressway in the Oyigbo Local Government Area. This particular disposal is a built up area with housing estates, schools, businesses and residential houses. In fact the Oyigbo Timber Market is within 1km radius of this site (Figure 3).

There has been a lot of outcry from the people of Oyigbo Local Government area of Rivers state against the sitting of the Obigbo landfill. The objections complained about odour and stench emanating from the landfill situated along the Aba-Port Harcourt major highway. The people who use the road, especially those who dwell within the vicinity of the landfill, have entitled this disposal area as “Amaechi Scent”, referring to the state Governor’s name. Also, groundwater pollution problems were reported by residents during the fieldwork, and these are common impacts of waste dumpsites on ambient environments. Other environmental challenges include aesthetics, loss of property values and noise pollution.

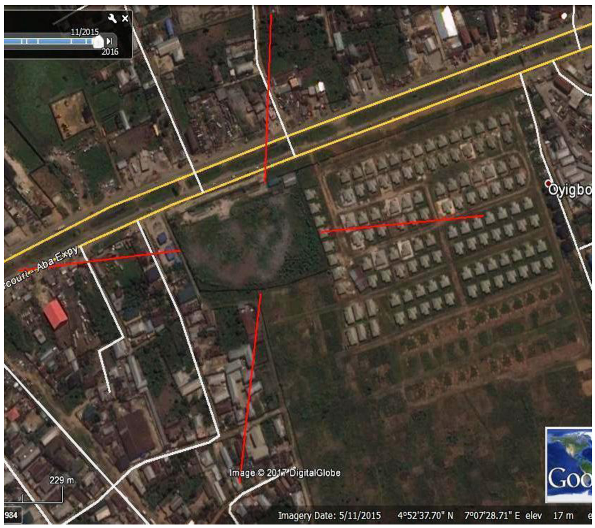

FIGURE 3 – Satellite image of Obigbo LFS planning area marked by red lines, which shows areas lying 250 metres from the edge of the landfills.

SOURCE: adapted from Google Earth (2017).

The Eneka-Igwuruta landfill (Figure 4) is located north of the City of Port Harcourt, along Igwuruta/Eneka road on Latitude 4°56’05.57”N, Longitude 7°01’58.47”E , and inside Ikwerre Local Government Area of Port Harcourt metropolis. The site is about 200m in length and 425m width, tapering from around 130m along Igwuruta/Eneka highway. The site is a co-disposal dumpsite with the nearest building being 200m away.

The Eliozu Landfill site is specifically located between (4° 53′ 08.85″N, 7° 00′ 44.99″E), around the New Airport Road in Obio/Akpor, Local Government Area of Rivers State. This is an upcoming residential area within the Port Harcourt Metropolis. It has a mixed development of residential houses, churches, business and a few micro industrial plants (Figure 5).

FIGURE 5 – Satellite image of Eliozo LFS planning area marked by red lines, which shows areas lying 250 metres from the edge of the landfills.

SOURCE: adapted from Google Earth (2017)

FIGURE 4 – Satellite image of Eneka LFS planning area marked by red lines, which shows areas lying 250 metres from the edge of the landfills.

SOURCE: adapted from Google Earth (2017).

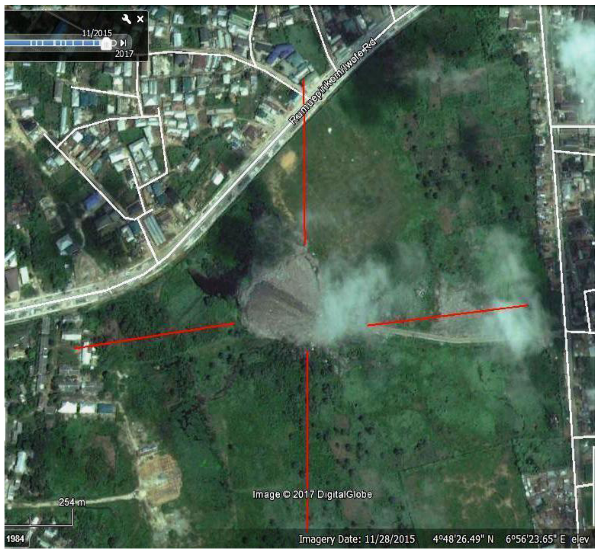

FIGURE 6 – satellite image of Rumuolumeni LFS planning area marked by red lines, which shows areas lying 250 metres from the edge of the landfills.

SOURCE: adapted from Google Earth (2017).

The Rumuolumeni site (Figure 6) is also a co-disposal landfill, located off the Rumuolumeni road, and has residential and commercial properties within 50 metres of its vicinity. Point location is 4°48'25.06"N and 6°56'27.35"E.

3. Methods

The Portable Real-Time Monitoring Technique using handheld instruments was applied in this study, which was carried out during the rainfall short break in August 2015. The portable real-time air quality monitoring allows rapid turn-around of data with relatively inexpensive digital instrumentation, which enables instantaneous results of emissions and other site conditions to be acquired on-site in real time. Because of this, decisions can be made for the protection of workers and off-site communities. Portable gas samplers and analysers use technologies involving portable flame ionization detection (FIDs) and PIDs. These technologies are able to generate levels of NMOCs, methane, and total VOCs. They can be used to rapidly and economically identify hot spots of pollutants of concern including NMOC, CH_4, or total VOCs within a dumpsite (Robertson & Dunbar, 2005).

3.1. Air quality and environment meteorological Analysis

The study used a combination of near surface air quality monitoring technique at heights above 30 cm from landfill surfaces and air quality measurements were also taken at 250 metres and 1 km downwind from the landfills (ATSDR, 2001). Particulate matter was measured using the ®Met One GT-321 One Channel Particle Counter, which has a high functionality that allows the rapid analysis of particulates in the range of 0.3, 0.5, 1.0, 2.0 and 5.0 microns. The Met-One particle counter generates accurate measurements of particulate contamination in particles per cubic foot in minutes and has a NIST traceable calibration in accordance with ASTM F649, ASTM F328 and JIS B 9921. The sampler takes a total of 10 samples. After this, it provides a mean that represents the result per location. A conversion factor from the Air Quality Sensor Network for Philadelphia-Data Validation-was used to convert $PM_{2.5}$ and Pm_{10} levels in μg/m, and particles/ft^3 were converted in □□/□^{3} using the equation described in Arling *et al*. (2010) for an easier comparison with EPA and WHO standards.

Noise levels were measured using the ®Extech 407730 Digital Sound Level Meter, while humidity, temperature, air velocity and light were measured using the ®Extech 45170 Hygro-Thermo-Anemometer-Light Meter. VOCs, methane, ammonia, SO_2, NO_2, CO and NO were measured using the MX6 iBrid™ (Industrial Scientific) Gas Monitor. Measurements were taken around 6am, 12 noon and 6pm, and results were presented as ranges that indicate a 24 hour analysis. The LandGEM, landfill gas emissions model (USEPA, 2005), version 3.02 was applied to the landfill gases generated from the landfills and later constrained by the Mexico Landfill Model (v.2, 2009), which is a 'tropical' version of the LandGEM. The geographical location of each sampling point was recorded using handheld GPS equipment (Garmin 76).

4. Results

4.1 Air Quality

Tables 1 and 2 describe the results for real time air quality sampling carried out in the landfills and within specified distances from the landfills in the windward direction.

Table 3 describes the conversion of sampled particulate matter from particles/ft^3 to □□/□^{3} using the equation described in Arling *et al*. (2010), which was made for an easier comparison with EPA and WHO standards. The formula developed for the supplement of the Air Quality Sensor Network for Philadelphia and for particulate matter monitoring categorized particulates into Pm2.5 and Pm10 and was applied in this study.

The Arling *et al.* (2010) equation is as follows:

PM Concentration (µg/m3) = Number of Partciles X 35.315 X Partcile Mass

Where,

The mass of a particle in the PM2.5 channel is 5.89E-7 µg and the mass of a particle in the PM10 channel is 1.21E-4 µg.

SO_2 was above the USEPA limits (75ppb) at the landfill sites, while the rest of the regulated gases were within acceptable limits. All categories of particulate matter were above acceptable limits in all the sites, apart from site 3 in Oyigbo LFS (1km away). Concentration of PM $_{<2.5}$ was slightly below the limits (21/25). The landfills studied also presented an increase in all categories of particulates and NO_2 downwind within the 250m radius, while concentrations diminished at about 1km from the LFS.

Other unregulated parameters ranged between 0.007 -0.5 ppm for NO; 0.2-0.6 for VOCs; 0.1-3ppm for NH_3, 0.03-56 for CH_4 and 0.00-0.08 for H_2S. All the gases had a general decreasing in concentration downwind. Noise levels were also within acceptable limits of 90decibels (USEPA, 2014). It should be noted that similar tendencies have been observed and reported to the Eneka-Igwuruta landfill (Igbagara *et al*., 2016) and to the Rumuolumeni landfill (Weli & Adekunle, 2014).

4.2. Emission Modelling

The LandGEM, landfill gas emissions model (USEPA, 2005), version 3.02, was applied to the landfills based on observation data and estimates provided by the Rivers State Environmental Sanitation Authority staff that operates the landfills. The landGEM is a screening tool based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste (MSW) landfills. The software provides a relatively simple approach to estimating landfill gas emissions. Model defaults are based on empirical data from U.S. landfills (USEPA, 2005). The following user inputs and assumptions are the basis for the operation of the software:

Landfill open year

Landfill closure year or design capacity

Annual waste acceptance rates from open year to current year or closure year

LandGEM is based on the gas generated from anaerobic decomposition of landfilled waste, which has methane levels between 40-60%. The data used and the results obtained from applying the landGEM code are presented in Table 4. The data applied in the LandGEM model was later constrained using the Mexico Landfill Model (v.2, 2009), which is a 'tropical' version of the LandGEM, and the results obtained presented an increase of approximately three and a half times in potential LFG generation rates.

5. Discussions

5.1. Locational analysis of LFS and Urban planning Implications

Considering the four landfill sites studied, the

TABLE 1 – Results of air quality sampling for Eliozo/Eligbolo and Standards.

Parameter	**Landfill N °4 53′ 38″ E °7 51′ 185″**	**250m (site2) N °4 55′ 526″ E °7 46′ 58″**	**1km (site3) N °4 53′ 22.17″ E °7 01′ 779″**	**STANDARDS**		
				USEPA (2012)	**Nigeria (DPR*)**	**WHO (2006) (µg/m³)**
SO_2 ppm	0.22 (220ppb)	0.00	0.00	75ppb	124ppm	20,000 (24-hour mean)
NO_2 ppm	0 - 0.5 (50ppb)	0 – 0.5(50ppb)	0.007(7ppb)	**100** ppb	197ppm	200,000 (1-hour mean)
NO ppm	0.2- 0.4	0.3	0 – 0.2			
VOCs ppm	0.6	0.2	0.03			
CH_4 ppm	36 - 53	23	0.06			
NH_3 ppm	0.3 - 3	0 – 0.3	0 – 0.1			
H_2S ppm	0.08	0.03	0.00			
Pm 0.3 µm (ppcf)	1, 702,002	1,720, 312	1,554,408	**15 - 35** µg/m³	60 – 230 (Total Suspended Particulate Matter- TSPM) µg/m³	**PM2.5: 25 (24-hour mean)**
Pm 0.5 µm (ppcf)	1,123,00	313, 821	168,300	**15 - 35 µg/m³**	60 – 230 (TSPM)	-
Pm 1 µm (ppcf)	118,354	751, 490	37,689	**15 - 35** µg/m³	60 – 230 (TSPM)	-

Pm 2 µm (ppcf)	52300	78, 444	18,850	**15 - 35** $\mu g/m^3$	60 – 230 (TSPM)	-
Pm 5 µm (ppcf)	2,546	7,776	630	**150** $\mu g/m^3$	60 – 230 (TSPM)	PM10: 50 (24-hour mean)
Wind speed	0.8-3.2	0.8 – 3.0	0.8 – 3.0			
Wind direction	SE	SE	SE			
R. humidity	54.5 - 65	54.5 - 60	54.5 – 60			
Temperature	34-36	32 -34	32 – 34			
Noise	46-58	38 - 46	32 – 36			

* DPR (2002) Environmental Guidelines & Standards for the Petroleum Industry in Nigeria.

TABLE 2 – Results of air quality sampling for Obigbo and Standards.

Parameter	**Landfill N °4 52′41.268″ E °7 7′ 26.695″**	**250m (site2) N °4 55′ 526″ E °7 46′ 58″**	**1km (site3) N °4 53′ 22.17″ E °7 01′ 779″**	**STANDARDS**		
				USEPA (2012)	**Nigeria (DPR*)**	**WHO (2006) ($\mu g/m^3$)**
SO_2 ppm	0.23 (230 ppb)	0.01(10ppb)	0.00	**75**ppb	124ppm	20,000 (24-hour mean)
NO_2 ppm	0.3 (30ppb)	0.5 (50ppb)	0.00	**100** ppb	197ppm	200,000 (1-hour mean)
NO ppm	5.2	0.3	0.2			
VOCs ppm	0.06	0.02	0.00			
CH_4 ppm	36	12	0.03			
NH_3 ppm	0.6	0.3	0.1			
H_2S ppm	0.06	0.03	0.00			
Pm 0.3 µm (ppcf)	1, 080,171	1,720, 312	1,554,408	**15 - 35** $\mu g/m^3$	60 – 230 (Total Suspended Particulate Matter- TSPM) $\mu g/m^3$	**PM2.5: 25 (24-hour mean)**

Pm 0.5 μm (ppcf)	190,044	313, 821	168,300	**15 - 35** $\mu g/m^3$	60 – 230 (TSPM)	-
Pm 1 μm (ppcf)	48,780	751, 490	37,689	**15 - 35** $\mu g/m^3$	60 – 230 (TSPM)	-
Pm 2 μm (ppcf)	26,874	38, 644	9,860	**15 - 35** $\mu g/m^3$	60 – 230 (TSPM)	-
Pm 5 μm (ppcf)	1,320	3,766	430	**150** $\mu g/m^3$	60 – 230 (TSPM)	PM10: 50 (24-hour mean)
Wind speed	0.8-3.2	0.4 - 0.8	0.8 – 3.0			
Wind direction	SE	SE	SE			
R. humidity	55.6 - 65	39.3 - 46	54.5 - 60			
Temperature	34-36.6	32 -34	32 – 34			

TABLE 3 – Converted particulate matter concentrations for Eliozo and Eligbolo landfills.

Landfill site	Parameter	Landfill site (LFS)	Site 2; 250m from LFS	Site 3; 1km from LFS	USEPA (2012) $\mu g/m^3$	WHO (2006)	Nigeria (DPR)
Eliozo	Pm <2.5 ppcf	52,300	78,444	18,850			230 (TSPM)
	$\mu g/m^3$	110	165	40	35 $\mu g/m^3$	25 $\mu g/m^3$	
	Pm >5 ppcf	2,546	7,776	630			
	$\mu g/m^3$	1,095	3,344	271	150 $\mu g/m^3$	50 $\mu g/m^3$	
Oyigbo	Pm <2.5 ppcf	26,847	38,644	9,860			230 (TSPM)
	$\mu g/m^3$	56.41	81.1	21	35 $\mu g/m^3$	25 $\mu g/m^3$	
	Pm >5 ppcf	1,320	3,766	430			
	$\mu g/m^3$	567.6	1,619.4	185	150 $\mu g/m^3$	50 $\mu g/m^3$	

TABLE 4 – LandGEM generated estimates of LFG from Port Harcourt landfills.

Parameter	Yearly Waste acceptance rates (tons)	Current Waste--in-place (short tons)	Total LFG (m^3/year)	Total methane (m^3/year)	Total CO2 (m^3/year)	Total NMOC (m^3/year)
Range	97,344-172,000	516, 516-292,229	7,431,000-4,204,000	3,716,000-2,102,000	3,496,000-2,102,000	29,720-18,380

$(\bar{x})$	269,344	404,372	5,817,500	1,236,800	2,799,000	24,050
$(\bar{x})$ 4 dump-sites	1,077,376	1,617,488	23,270,000	4,947,200	1,119,6000	96,200

Eneka and Eliozo sites seem more optimally located in terms of direct impact on the populace, contrary to Obigbo and Rumuolumeni LFS, which are located within close proximity to dense residential and commercial buildings (Figures 3-6). From the property count conducted and supported by satellite imagery (Figures 3-6), over 200 properties are affected by the Rumuolumeni dumpsite immediate planning area (marked by the red cross on Figures 3-6), while about 500 properties are affected by the Obigbo landfill area. The Eneka and Eliozo landfills have less than 100 properties within their immediate planning area. Therefore, for the Obigbo and Rumuolumeni sites, about 5,000 people who dwell or work within the planning area of these landfills may be directly affected, according to the national average family size of 5 people per household (NPC/ICF, 2014) and to the fact that these properties exist as mixed residential and commercial/industrial housing facilities.

Although the Eneka and Eliozo landfills may have lower impacts in terms of human population, it should be noted that the Eliozo LFS is located near wetlands which form part of the headstream of the Rumuobiakani River. In addition, as concluded by Igbagara *et al.* (2016), the high levels of pollutants from the Eneka LFS put people who work at the landfill site, residents around the landfill and most especially students of the Charles Dale Memorial International School (which is located within the 250m planning area and downwind of the landfill site) in a vulnerable position to pollution from the site. Weli & Adekunle (2014) also reported dangerous concentrations of LFG gases up to 200m from the centre of the Rumuolumeni landfill, while results from this study (Tables 1 and 3) showed an increasing concentration of pollutants downwind up to 250m from the centre of the Obigbo and Eliozo landfills.

We think that the closure of these landfills, especially the Obigbo, Rumuolumeni and probably the Eliozo sites, would be a great solution to the air and potential water pollution problems caused by these landfills. However, the re-engineering of the Eliozo landfill to prevent leachate contamination of groundwater and neighbouring wetlands is important. The challenge here is that landfills are known to continue to produce pollutants even after 50 years of their closure (Robertson & Dunbar, 2005).

5.2. Environmental and Health Effects of Port Harcourt Landfills

Through The Clean Air Act, the USEPA (2012) has set standards in the USA for pollutants considered harmful to public health and to the environment. The Clean Air Act identifies two types of national ambient air quality standards: *primary standards,* which are directed to public health protection and also to the health protection of "sensitive" populations such as asthmatics, children, and the elderly; and s*econdary standards,* which are directed to public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

Robertson & Dunbar (2005) and Zdeb & Lebiocka (2016) declared that "typical" landfill gases by percentage volume include CH_4 (45 to 60ppm), with concentrations in ambient air occurring around 0.0002%. Landfills are the single largest source of man-made methane emissions. CO_2 (40 to 60ppm) occurs naturally at a small concentration (0.03%) in the atmosphere. NO_2 has concentrations of about 2 to 5ppm, while ammonia has 0.1 to 1ppm and CO (0 to 0.2) has atmospheric concentrations lower than 0.00001%. Therefore, this study reveals that the Port Harcourt landfill has typical gas emission ranges.

On the other hand, landfill gases (LFG) are naturally generated by methanogens that decompose complex organic materials into organic compounds of lower molecular weight. Consequently, landfill gases are made up of methane, carbon dioxide (CO_2) and non-methane organic compounds (NMOC) (USEPA, 1995; Pleissner, 2016). Also, Ground level ozone formation is the first specific health and welfare effect of the production of LFGs. Ground level ozone is created by sunlight acting on nitrogen oxides (NOx) and NMOCs in ambient air. Ozone may lead to health effects such as aggravation of existing respiratory diseases, alteration of pulmonary functions, damage to lung structure and adverse effects on blood enzymes, the central nervous system and the endocrine system. Ozone also presents other welfare effects such as deterioration of certain synthetic materials, such as rubber, reduced plant growth, crop yield and necrosis of plant tissue. A second concern is the cancerous and non-cancerous effects of various NMOCs (USEPA, 1995).

Regarding the emitted gases from the landfills, SO_2 is a criteria gaseous pollutant formed during the process of burning garbage. It can be oxidised within airborne water droplets form sulphuric acid because it is soluble in water. It is therefore important in the formation of acid deposition or 'acid rain' in conjunction with the nitrogen oxides. The Nitrogen oxides (NOx), which are nitrogen dioxide (NO_2), nitrous oxide (N_2O) and nitric oxide (NO), on the other hand, are formed by the combination of nitrogen (N_2) with oxygen (O_2) in the atmosphere. Their lifespan in the atmosphere ranges from one to seven days for nitric oxide and nitrogen dioxide, while nitrous oxide may remain in the atmosphere for up to 170 years. Nitrogen oxides are typically created during combustion processes, and are major contributors to smog formation and are also an important factor in acid deposition.

Although the nitric oxide variant has no colour, odour or taste and is non-toxic, it is readily converted in the air to nitrogen dioxide. NO_2 is a criteria air pollutant, and may cause numerous adverse health effects. It absorbs blue light, which results in a brownish-red cast to the atmosphere and reduced visibility (ISE, 2009). At high concentration levels, nitrogen dioxide is potentially toxic to plants; it can injure leaves and reduce growth and yield. In combination with either ozone (O_3) or sulphur dioxide (SO_2), nitrogen dioxide may cause injury at even very low concentration levels. As one of the components of smog, nitrogen dioxide is known to irritate the lungs and increase susceptibility to respiratory infections. Nitrous oxide, on the other hand, is a greenhouse gas and contributes to ozone depletion (CASA, 2014). Many NMOC identified in LFG are either known or suspected carcinogens, and have the potential to produce non-cancer health effects as well, such as adverse effects on the kidneys, liver and central nervous system, since many of the NMOC are Hazardous Air Pollutants (HAP's) (USEPA, 1995).

In addition, concentrations of particulate matter (PM_{10}) in the vicinity of the landfill were above the national average of 123.6 µg/m^3 (Efe, 2008), but compatible to results from other studies. For instance, Chalvatzaki *et al.* (2010) in a study of particulate matter concentrations at landfill sites in Crete, Greece, concluded that the average concentrations of PM_{10} inside the landfill facilities ranged between 113 and 4,597 µg/m^3, which is similar to the over 500-3,344 µg/m^3 found in the landfill sites and within 250 metres from their vicinity.

The WHO (2006) concludes that the evidence on airborne particulate matter (PM) and its public health impact is consistent with the adverse health effects presented by urban populations that experience exposure, in both developed and developing countries. The health effects are numerous, but the ones that predominate are those related to the respiratory and the cardiovascular systems. All population is affected, but susceptibility to the pollution may vary with health or age. The risk of various outcomes increases with exposure and there is little evidence to suggest a threshold under which no adverse health effects could be foreseen. In fact, the low end of the range of concentrations, at which adverse health effects have been demonstrated, is not greatly above the background concentration, which for particles smaller than 2.5 µm ($PM_{2.5}$) has been estimated to be 3-5 µg/m^3 in both the United States and western Europe. The epidemiological evidence shows adverse effects of PM following both short-term and long-term exposures.

5.3. Energy Supply implications of Port Harcourt Landfills

Global investment in renewable energy, without considering big hydropower energy sources, has grown to US$ 214 billion in 2013; while total renewable energy investment in Africa has risen from US$750 million in 2004 to US$ 3.6 billion in 2011, with South Africa, Egypt and Kenya being key investors. However, investments are projected to hit US$7.7 billion in 2016. It is important to note that Nigeria, with a population of about 180 million people, sadly has an annual electricity generation capacity of only 4,000MW, which is energy per capita lower than 27 watts. The electrification rate in Nigeria was about 52% in 2011, leaving approximately 84 million people without access to electricity. Consequently, this created a renewable energy market of up to US$ 7.7 billion, almost as large as the ones of South Africa, Kenya and Egypt put together (Businessday Newspaper, 20th January, 20, 2015).

Although Port Harcourt is an oil city, it suffers from inadequate power production and distribution. However, Port Harcourt landfills have the capacity to produce approximately 3,878,333.3 -11,447,860 KWh /year of electricity; based on the established biogas calorific value of 6 KWh/m^3, which corresponds to about half a litre of diesel oil and can be utilised directly as a heat source or to produce electricity (Sacherm *et al*., 2017). Biogas is a mixture of methane, carbon dioxide, water and hydrogen sulphide produced mainly during the anaerobic digestion of organic matter such as municipal solid wastes (Lo *et al*., 2010).

According to the USEPA (2014), MSW landfills are the third-largest human-generated source of methane emissions in the United States, releasing an estimated 83.1 million metric tons of CO_2 , which is equivalent (MMTCO_2e) to the atmosphere of 2012 alone. Methane generated from landfills can be used to generate electricity. Given that all landfills generate methane, it makes sense to use the gas for beneficial purposes, such as energy, rather than emit it into the atmosphere where it causes greenhouse and ozone problems. Methane is a very potent greenhouse gas that is a key contributor to global climate change (25 times stronger than CO_2). Methane also has a short (10-year) atmospheric life. Because methane is both potent and short-lived, reducing methane emissions from MSW landfills is one of the best ways to achieve a near-term beneficial impact in mitigating global climate change.

It is estimated that a properly engineered landfill can capture 60 to 90 percent of the methane emitted from a landfill. The captured methane is destroyed (converted to water and to the much less potent CO_2) when the gas is burned to produce electricity, thereby reducing global warming effects. Also, producing energy from LFG avoids the need to use non–renewable resources such as coal, oil, or natural gas to produce the same amount of energy. This can reduce gas end–user and power plant emissions of CO_2 and criteria pollutants such as sulphur dioxide (which is a major contributor to acid rain), particulate matter (a respiratory health concern), nitrogen oxides (NO_X), and trace hazardous air pollutants (USEPA, 2014); and also reduce power generation and distribution problems of Port Harcourt city. LFS can also be converted to neighbourhood power plants, which may create jobs and a more vibrant economy.

6. Conclusion

This study aimed to provide a perspective on the effects and potentials of urban waste management in the city of Port Harcourt, Nigeria, using real time measurement techniques and LFG modelling. It was concluded that landfills in the city are co-disposal landfills and receive both municipal solid waste (MSW) and hazardous or toxic wastes. Co-disposal landfill gases (LFG) typically include higher vapour concentrations of non-methane organic compounds (NMOCs) when compared to an MSW landfill that has not received any significant quantity of toxic or hazardous compounds.

It was also discovered that SO_2 was above the USEPA limits (75ppb) at the landfill sites, while the rest of the regulated gases were within acceptable limits. All categories of particulate matter were mostly above acceptable limits in all sites and tended to increase up to 250m radius from landfill sites. Landfills can also be veritable sources of biogas, which can help to solve the incessant problem of power production and distribution of Port Harcourt city.

In the light of the foregoing, it is hereby recommended that: the Obigbo and the Rumuolumeni landfills be closed, as they are a great nuisance and a serious threat to the people and the environmental health of the study area..In addition, the government should acquire all properties, and adequately compensate all owners, within the “planning area” of each landfill, which are located 300 metres from the centre of each of the Port Harcourt landfills. These measures have to be done in order to safeguard the health of the people who live and work around the landfills, and forestall aesthetic losses of properties around the vicinity of the landfills. Finally, the government of Rivers State should consider the creation of four properly engineered landfills with full capacity to capture leachate and convert LFG into power. These landfills should also have an integrative design to serve as neighbourhood power generating plants. This can be done by public-private partnerships and will help to solve power problems, reduce environmental pollution and global warming effects and minimize the threat to the ozone layer. It will also generate the much needed employment and businesses identified by the study.

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