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Assessment of Spatio- Temporal Variation of Methane Gas Emission from Landfills in Kano Metropolis, Nigeria

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Abstract— *This study assessed the emission of methane (CH4) gas from four (4) government approved landfills within Kano Metropolis with a view to providing a database on Methane gas emission for possible use by renewable energy projects and for effective urban environmental management and governance. A Methane gas detector (E6000 Portable Multi-gas detector) was used to assess methane from the landfills in the morning (8:00am – 12:00noon), afternoon (12:00pm – 3:00pm) and evening (4:00pm – 6:00pm) for twelve (12) days (for about 2 weeks) between the month of April and May 2023. It was discovered that the rate of methane gas emission was higher in the evenings, the rate of methane gas emission differs significantly across the selected landfills and the environmental implication of methane gas emission in the study area was manageable. From the study, the rate of Methane gas emission within Kano metropolis is reasonably high and okay for renewable energy generation. So, it is advisable that the government utilize it for different purposes. Also, more government approved dump sites was recommended due to the fast growth rate and development within Kano Metropolis and the government still needs to do more in providing a more appropriate means of waste disposal in some of the areas within the Metropolis.*

I. INTRODUCTION

Methane is also a short-lived climate pollutant with an average atmospheric lifetime of about 12 years (Intergovernmental Panel on Climate Change, IPCC, 2007). Also, the second largest climate change agent behind carbon dioxide and one of the six greenhouse gasses (GHGs) identified in the Kyoto Protocol, with a global warming potential of 25 years over 100(Almer & Winkler, 2017). According to the IPCC Fourth Assessment Report, total methane (CH_4) and waste management emissions accounted for 14.3 percent and 2.8 percent of global GHG emissions in 2004, respectively (IPCC, 2007). Waste management CH_4 emissions contributed 4 percent of total global GHG emissions in 2010, with approximately half of both landfill and wastewater treatment from Metropolitan landfills (Worden et al., 2017). Metropolitan solid waste landfill CH_4 emissions increased steadily from 16.50 Mt in 1970 to 29.50 Mt in 2008, with a total increase of 78.79%. Approximately, 73% of safe disposal of metropolitan solid waste was landfilled in developed countries in 2012. Landfill is currently dominated by solid waste disposal, and will remain dominant across the globe (Naveen, et-al 2017). With the growth of the economy, the progress of urbanization and the improvement of living standards of people, both waste generation and landfill are growing substantially. Comprehensive and reliable calculation of landfill CH_4 emissions is becoming increasingly important in global waste recycling and reduction of CH_4 emissions (Nabavi-Pelesaraei, et-al, 2017). The regional specific emission factors and comprehensive CH_4 emission inventory are important for provincial-level regional GHG inventories and climate change programs. In Kano metropolis, like other cities in the developing world, several tons of municipal solid wastes are left uncollected on the streets each day. Around the metropolitan area are clogging drains, creating a feeding ground for pests that spread disease and creating a myriad of related health and infrastructural problems (Vergara & Tchobanoglous, 2012). A substantial part of the urban residents in the old city and suburban informal settlements of the Kano metropolis also have little or no access to solid waste collection services. Inadequate management of these wastes can have negative impacts on people and the environment (Oke, 2008). The need to adequately manage solid wastes in Kano metropolis is critical to the good health and well-being of the indigenes as well as environmental sustainability. Kano metropolis is constrained by the inadequacy of waste management. For instance, the entire metropolis with eight Local Government Councils (LGC) has only a single central waste management agency (Nabegu & Wudil, 2008). But a metropolitan city comprising of eight Local Government areas is too large for a single waste management agency like REMASAB to handle its collections. More so, the socioeconomic and demographic characteristics of households in the Kano metropolis needs to have numerous waste management agencies to handle waste collection and management is critical to achieving sustainable development goal 11 and 13 (Abila & Kantola, 2013). The study assesses the spatial and temporal variation of methane gas emission from the landfills in the Kano metropolis.

II. THEORETICAL FRAMEWORK

Methane Emission

Global emissions of methane are a big part of global greenhouse gas emissions. Atmospheric methane has an approximate 100-year global warming potential of 34, indicating that a ton of methane released into the atmosphere produces about 34 times the atmospheric warming as a ton of carbon dioxide over a 100-year period (Slack et al., 2005). Atmospheric concentrations of methane have exceeded pre-industrial levels of nearly two and a half time, or 3.2 billion tons. While methane absorbs much more heat than the same carbon dioxide mass, it persists in the atmosphere for only about a decade, while carbon dioxide theoretically warms for a much longer period of time assuming no shift in carbon sequestration levels (Worden et al., 2017). At a time, scale of 20 years, a mass of methane is about 85 times more powerful than carbon dioxide in warming the Earth (Pires et al., 2011). But at a time, scale of 100 years, it is estimated to be only about 28-34 times more powerful, on the basis that carbon dioxide will not be sequestered and will continue to warm the Earth for decades after the methane has gone away. 60 percent of methane emissions are caused by humans and livestock, and about 40 percent of methane emissions come from natural sources such as wetlands (Scheutz & Kjeldsen, 2004). Human sources include livestock, in particular animal farming and rice processing, industrial waste and fugitive pollution including the energy sector. At least 30 per cent of artificial methane emissions are caused by grazing animals such as cattle and sheep along with other species (Vergara & Tchobanoglous, 2012). Gas, natural gas and coal fleeting emissions contribute between 25-34 per cent of artificial methane emissions. Around 18 per cent of artificial methane emissions are caused by human waste including landfill and wastewater. Rice production produces an abnormal emission of around 7 to 20 per cent. Wetlands make up about 30%, while natural sources other than wetlands make up about 10% (Scheutz & Kjeldsen, 2004).

Landfills

The idea of sanitary landfills first began regardless of the major risks faced by open dumps on human and environmental health (Benson et-al 2007). This removed the open dumps that posed serious health threats and continues to pose them. Literally, these simple landfills were naturally occurring depressions in the ground or sand or gravel dumps, and borrowing areas that were filled with waste and then covered with a minimal amount of land (Warith, 2002). Sanitary landfilling is a systematic manner of lying solid waste between layers of soil to facilitate the waste's gradual decomposition. So, modern landfills are highly engineered containment systems, developed to minimize the adverse effect of metropolitan solid waste on the environment and human health (Vrijheid, 2000). In the case of modern sanitary landfills, a liner system is used to separate the waste from the ground water, and rain water is prevented from entering the waste by a landfill cap. This is called dry-tomb landfilling which minimizes the potential environmental impact of the leachate by reducing its generation and restricting it within the landfill (Slack, et-al 2005). Leachate is water that has moved through the landfill and collected water-soluble compounds from the waste. Leachate flowing out of landfills should not be permitted to contaminate the surrounding soil and groundwater, as it may cause serious damage to the environment (Ehrig, 1983). This landfilling dry-tomb method is primarily a solid waste storage method which needs land-use restrictions and continued maintenance. In the absence of perpetual maintenance, landfill caps can fail allowing for rainwater infiltration and subsequent unregulated leachate generation. This leachate can pose serious health risks to the community and the environment if the liner system also fails (Mukherjee, et-al 2015).

Factors Influencing Methane Emissions from Landfills

Methane is produced as a result of the anaerobic degradation of organic waste at municipal solid waste (MSW) landfills. The EPA reported that, in 2016, U.S. landfill methane emissions were approximately 107.7 million tons of carbon dioxide equivalent (Mt CO_2 e), representing approximately 16.4 per cent of total U.S. anthropogenic methane emissions in 2016, and were the third largest source of methane emissions after enteric fermentation (the highest) and natural gas systems (Nozhevnikova et al., 1993).At global level, it was estimated that in 2005, methane emissions from solid waste landfill were 794.0 million tons of CO_2 e, again, after enteric fermentation and natural gas & oil systems, landfilling was the third largest source of methane emissions. Since the United Nations Framework Convention on Climate Change (UNFCCC) requires that Annex I Parties use GWP values from the IPCC Fourth Assessment Report (AR4), many of the data referred to in this report have been calculated according to this requirement (Pachauri & Reisinger, 2007). Hence, the GWP value of methane used in this report is 25 when converting units between carbon dioxide equivalent and actual methane emissions, unless otherwise stated. The readily degradable organic compounds on the outer surface of the landfill (to a depth of approximately 1–1.5 m) are aerobically oxidized shortly after MSW's deposition (Eiselt, 2007). The aerobic reaction requires oxygen in ambient air to degrade organic matter and is similar to combustion since CO_2, H_2O, and heat are produced as end products by the reaction (Naveen et al., 2017). Themelis and Kim have proven U.S. composition C, H, O. Formula C6H10O4 will represent MSW. The aerobic compostage reaction can therefore be expressed as follows:

$$C6H10O4 + 6.5O_2 \rightarrow 6CO_2 + 5H_2O$$

Generally, the aerobic process lasts only for days or a few weeks; after this period, the landfilled materials are covered with newly deposited wastes and the further reaction proceeds anaerobically. Both the aerobic and anaerobic reactions are biochemical and require the presence of different types of bacteria (Themelis, Kim, & Brady, 2002).

III. MATERIALS AND METHOD

Study Area

Kano is the largest city in northern Nigeria. It is located between latitude 12º 25 to 12º 40 N and longitude 8º 35N to 8º 45E. The provisional population figure from the 2006 census for Kano metropolis is 2,828,861 representing 30% of the state. The burgeoning population growth put enormous pressure on the existing waste management facilities as rapid growth of urban income has also improved the living standards of urbanites leading to changes in consumption patterns which leads to higher per capita waste generation.

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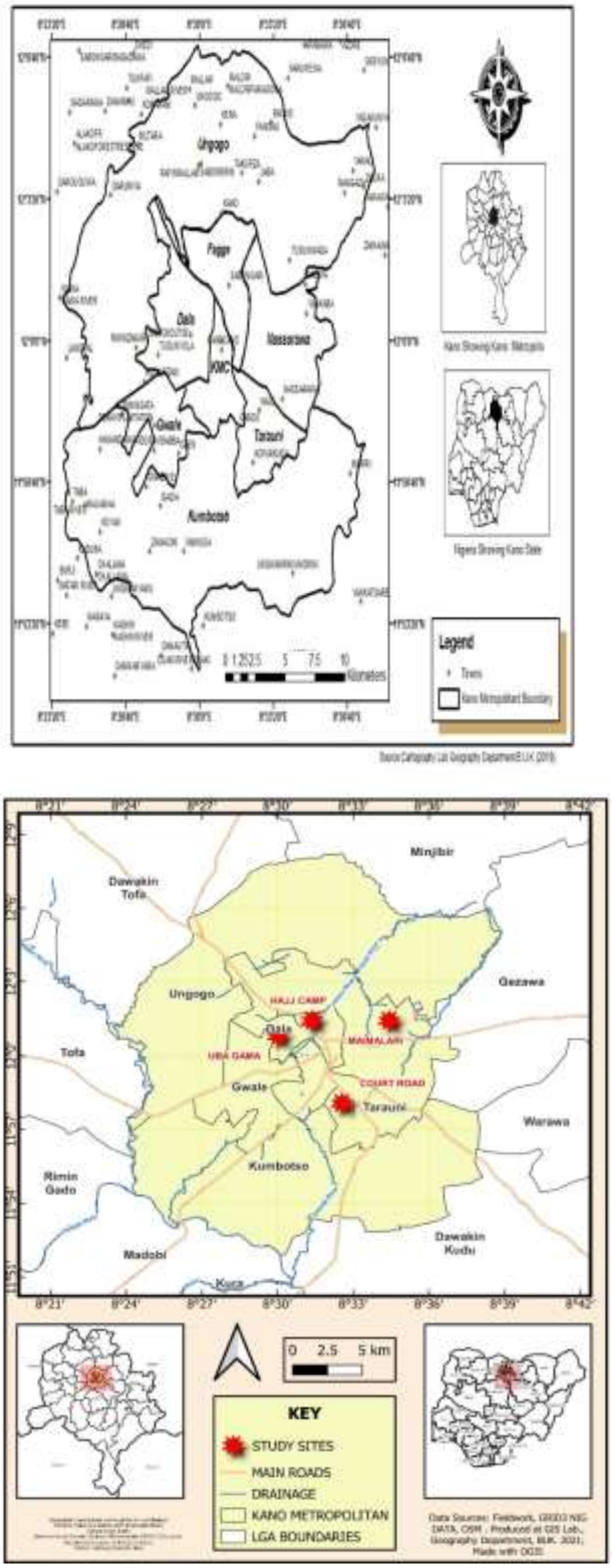

Figures 1. Location of the Study Area and Locations of the four (4) Dump sites in the study area

Method of Data Collection

The scattered set of Z- value (methane gas retrievers) which was retrieved or collected using the E6000 Portable Multi-gas Detector was tied to X-Y coordinates which was collected using a hand-held GNSS (Garmim eTrex GPS) from landfills in the study area where methane gas data was recorded using the device Global Navigation Satellite System (GNSS), also, spatial attributes (X and Y) of points where oxygen was retrieved, was coordinated using GNSS device. The X, Y coordinates points was used as the spatial distribution of the phenomena under study. Data was converted to comma-separated values (CSV) delimited format. This enabled usage of the data in GIS environment. Running of kriging interpolation was carried out with data in GIS environment. This determined cell values using a linearly weighted combination of a set of the study area sample points. This method will assume that the variable being mapped decreases in influence with distance from its sampled location. This showed the spatial distribution of methane gas and its intensity of impacts on populace residents around landfill sites. A grid line cell was also made using the data frame properties in the GIS environment (ArcGIS 10.4.1). The volume of oxygen was measured and recorded from 3 multiple 100 meters away from the source point's landfills otherwise called focal points. This was from North, East, South, and West. It was aimed at estimating the populace vulnerable to methane gas impact in the study area, that is, points areas with a low volume of oxygen indicate high vulnerability to methane gas.

Method of Data Analysis and Presentation

Landfills were sampled and studied in Kano Metropolis. Methane and Oxygen gas were retrieved with a gas detector device from different landfills as well as multiple 100 meters distance points from focal point landfills in the study area. Spatial attributes, X, Y (eastings and northings) of landfills, as well as Oxygen level, points at schools, hospitals, and households. Methane data was transformed to CSV format in Microsoft Excel 2019 environment. CSV data was transformed or exported into .tiff file format in a GIS environment with ArcGIS 10.4.1 software. AOD in the .tiff file was overlaid on the shape file of the study area extent. Methane data went through kriging interpolation analysis in a GIS environment; Maps and chats were used to show spatial variability as well as vulnerability estimate of Methane gas in the study area and of the populace resident in the study area; still further, analysis in the SPSS environment produced a statistical description of populace perception of the management of methane gas in the study area.

From the above Table 1, Methane gas emission differs significantly across the selected landfills in Kano Metropolis having the highest emission of 669.92ppm. Methane gas emission differs significantly according to time, with highest emission in the evenings (669.92ppm).

Spatial Distribution of Landfills in Kano Metropolis

Twelve percent of global methane emissions come from landfills, making them one of the main sources. Instead of letting landfill methane leak into the atmosphere or spread as garbage, it can be extracted, contained, and used as a somewhat clean energy source for producing heat or electricity. There are two ways that this helps the climate: it reduces emissions from landfills and replaces potential uses of coal, oil, or natural gas. Kano state has several dump sites, but there are only four (4)

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government approved dump sites in Kano, which were our main focus in this study. Most of these dump sites were close to residential houses, posing lot of risks to the populace.

TABLE 1. Methane Gas Retrievals

Day/Period	Station 1 (Gg)			Station 2 (Gg)			Station 3 (Gg)			Station 4 (Gg)		
	Morning	Afternoon	Evening	Morning	Afternoon	Evening	Morning	Afternoon	Evening	Morning	Afternoon	Evening
Day 1	119.58	155	215.12	292.53	396.48	539.78	155	215.12	292.53	238.54	323.31	443.54
Day 2	121.98	158.73	220.65	299.95	406.49	551.61	158.73	220.65	299.95	244.9	331.54	448.45
Day 3	124.49	162.67	226.37	307.53	408	563.44	162.67	226.37	307.53	251.41	340.07	468.39
Day 4	127.13	166.9	232.36	315.3	429.53	575.27	251.41	340.07	468.39	121.98	158.73	220.65
Day 5	129.86	171.52	238.54	323.31	443.54	587.1	257.99	348,73	481.66	124.49	162.67	226.37
Day 6	132.66	176.54	244.9	331.54	448.45	598.93	264.65	357.71	491.59	127.13	166.9	232.36
Day 7	135.55	181.93	251.41	340.07	468.39	610.76	271.4	367.02	504.51	198.85	271.4	367.02
Day 8	138.52	187.54	257.99	348,73	481.66	622.6	278.31	376.68	516.12	198.93	278.31	376.68
Day 9	141.57	193.24	264.65	357.71	491.59	634.43	288.02	386.72	527.95	209.72	288.02	386.72
Day 10	144.73	198.85	271.4	367.02	504.51	646.26	171.52	238.54	323.31	181.93	251.41	340.07
Day 11	148.02	198.93	278.31	376.68	516.12	658.09	176.54	244.9	331.54	187.54	257.99	348,73
Day 12	151.44	209.72	288.02	386.72	527.95	669.92	181.93	251.41	340.07	193.24	264.65	357.71

Key:
Units (ppm)
Gg (Gas generated)
Station 1 – Mai malaria dump site
Station 2 – Hajj camp dump site
Station 3 – Uba Gama dump site
Station 4 – Court Road dump site

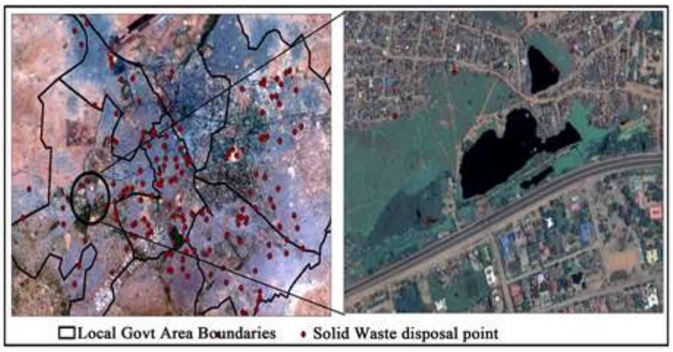

Figure 2. Distribution of Solid waste disposal sites in the study area.

It was observed that dump sites serve as places of work for scavengers who sort, sell and buy waste materials including waste plastic materials, nylons, discarded sachets of water, electronic wastes, clinical wastes and so on.

Spatial Variability

When a quantity is measured at several spatial locations and shows varying values at each place, this is known as spatial variability. Spatial descriptive statistics like the range can be used to evaluate spatial variability. It is the difference or variation (in terms of population, population density, GDP, life expectancy) over an area of the earth surface.

Methane Gas Emission from Landfills

Methane is produced in municipal solid waste (MSW) landfills when organic waste breaks down anaerobically. An estimate of 107.7 million tons carbon dioxide equivalent (Mt CO2 e) of landfill methane emissions occurred in the United States, according to the United States Environmental Protection Agency (US EPA, 2016). Once MSW is disposed into landfills, it undergoes aerobic decomposition, which produces a very small amount of methane (CH_4). Methane emission from landfills contributed to the total greenhouse gas emission in the Netherlands by 6% in 1990 (Olivier et al., 2017). The first objective of this study was to establish whether methane gas emission differs significantly across landfills in Kano Metropolis. In line with this objective, a hypothesis that; Methane gas emission differs significantly across landfills in Kano Metropolis was formulated. This hypothesis was tested using Analysis of Variance (ANOVA). The results of the ANOVA, suggested a significant variation in the methane gas emission across landfills in Kano Metropolis (sig =0.000 < 0.05), and therefore, validating hypothesis one.

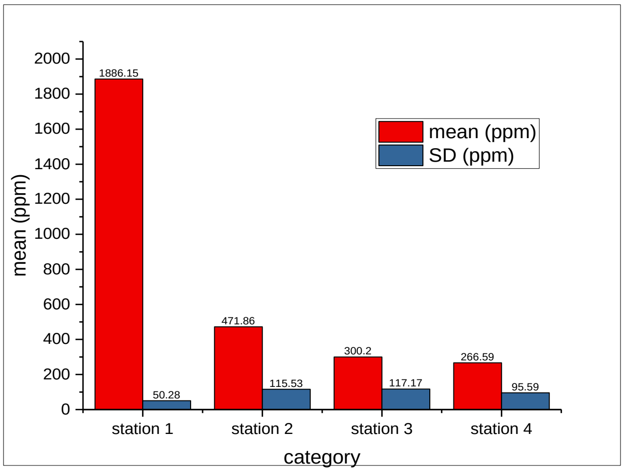

Figure 3. Methane Gas Emission from Landfills

Figure 3, presents the mean methane gas emission across the selected landfills together with their standard deviations. Figure 4. verifies that these means were significantly different from each other. From figure 4, the significant value (0.000) was less than 0.05, hence we reject null hypothesis and conclude that methane gas emissions significantly differ across the selected landfills in Kano Metropolis. This is because the amount of waste in each of these landfills differs from each other and the amount of each content of the waste also differs. The rate of decomposition of these wastes also differs. Thereby, making the rate of gas emissions from these landfills to significantly differ from each other. The implication of the above mentioned

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is that, the rate of damages that can be caused from the emissions that comes from these landfills may also differ from each other. From Table, the mean methane gas emission for station 2 was highest, followed by station 3.

Temporal Variation of Methane Emission

The word 'Temporal' is relating to time. With respect to the above study, it relates to the time variation in which methane emission takes place in the various landfills understudy. Readings were taken three times a day, for both morning, afternoon and evening. The difference in the times were studied, hence, temporal variation of methane gas emission within the four (4) approved dump sites within Kano Metropolis were studied. Temporal variability largely explains top-down / bottom-up difference in methane emission estimates from a natural gas production region (Vaughn et – al, 2010). The second objective of this study was to establish whether methane gas emission differs significantly according to time in Kano Metropolis. In line with this objective, a hypothesis that; Methane gas emission differs significantly according to time in Kano Metropolis was formulated. This hypothesis was also tested using Analysis of Variance (ANOVA). The results of the ANOVA as indicated in figure 4, suggested a significant variation in the methane gas emission according to time in Kano Metropolis (sig =0.000 < 0.05), and therefore, validating hypothesis two.

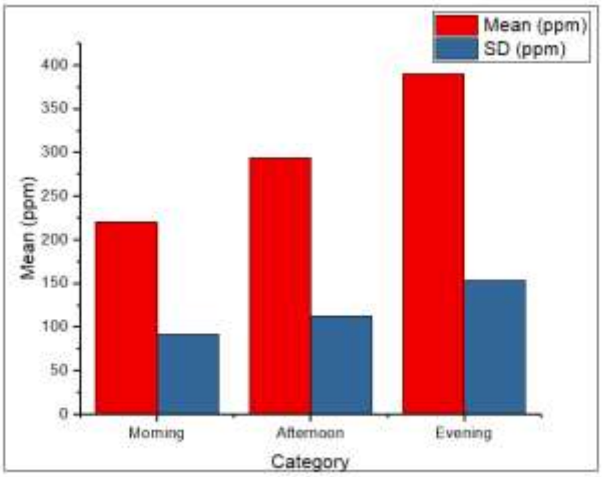

Figure 4. Temporal variation of Methane gas emission.

Figure 4, presents the mean methane gas emission according to time together with their standard deviations. Figure 4. Verifies that these means were significantly different from each other. From figure 4., the significant value (0.000) was less than 0.05, hence we reject null hypothesis and conclude that methane gas emissions significantly differ according to time in the selected landfills in Kano Metropolis.

From the above study, the rate of emission was higher in the evenings and this is because, the landfills may have experienced a lot of heat due to sunshine all through afternoon, thereby, making the rate of methane emission in the evenings to be very high. The higher the temperature in the landfills, the higher the rate of emissions within the landfills and vice - versa. This also implies that; the increase in temperature is directly proportional to the increase in the rate of methane emission in the landfills.

From figure. 4, the mean methane gas emission in the evening was highest, followed by afternoon.

IV. Conclusion and Outlook

This study assessed the emission of methane from the four (4) major Governments approved landfills within Kano Metropolis. Readings were taken with a Methane gas detector in the morning, afternoon and evening, for twelve (12) days which is about two (2) weeks. It was observed that the rate of methane gas emission was higher in the evenings due to excess heat (increased temperature). The higher the temperature, the higher the rate of methane gas emission and the lower the temperature, the lower the rate of methane gas emission. The increased temperature was usually due to increased sunshine in the afternoon which heats up the landfills, hence, making it have a higher temperature that helps to fuel the rate of methane gas emissions from the landfills. Consequently, observed that the higher the rate of emission, the higher the odour that comes from the landfills and the higher the rate of damages caused to the people that are resident there. The rate of Methane emission from the study area, are reasonably high. Kano State Government can generate Methane from landfills which can be used for different purposes. The Methane can be trapped and used as a renewable energy instead of allowing it to keep polluting the environment and contributing more to climate change. There are many options available for converting landfill gas (LFG) into energy. Different types of LFG energy projects are grouped below into three broad categories;

- Electricity generation
- Direct use of medium-Btu Gas, and
- Renewable Natural Gas.

None of the above is being used by Kano State government instead, they are left unused. Though there was no any form of feasibility study done on the cost benefits of the above but it is something the state government can buy into and improve the state. The Government still needs to do more in providing a more appropriate means of waste disposal in some areas within the Metropolis. Waste drums should be provided in these areas and disposed by Kano State Refuse Management Board (REMASAB) when it's filled up. More approved dump sites are need in the state because of the rate of expansion that is really going on in the state now. There is increase in population and more areas within the metropolis is being developed, with a lot of people moving in. for example, areas like Jaba (close to the airport) and Hotoro by pass has in recent time, had more population in. Also, if possible, chemicals should be provided to reduce the kind of bad odours that comes from these landfills. It should be sprayed regularly to reduce the bad odour from the landfills.

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