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Assessment of Municipal Solid Waste Generation, Management Practices and Waste-To-Energy Potential In Nigeria: A Review

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ABSTRACT:

World population indicates two to three billion inhabitants have inadequate sanitation, waste collection and disposal services particularly in the developing countries resulting in poor health, low productivity and economic consequences. This paper explored previous empirical and reviewed research works centered on generation rates, energy potential, management practices and challenges of Municipal Solid Waste, MSW service delivery. Results have showed that average generation rates for MSW are in the range of 0.31 kg/person/day to 1.23 kg/person/day. Reported daily delivery of tons of MSW for a Nigerian city could generate between 30 to 52 MWh of electricity with 20,198.89 kJ/kg of CV producing energy equivalent of 36.95 MW/day, while 584 tons/day of MSW could offer about 41 MW Electrical Power (EPPMSW) and Power to Grid of 27 MW. The work revealed that about 947981358 kWh/year of energy and $131769409/year as revenue can be obtain from MSW, while an estimated $493.3 million to $16.4 billion annually is feasible from MSW on daily basis from 34 million Nigerians living in the cities. Biogas production of about 1.82 billion Nm^3 and 1085688 tons of methane gas from Nigerian cities annually is also envisage from MSW. Prominent MSW management practices currently adopted by the people are open dumping, landfill, open burning, street/stream/river dumping, while incineration method is seldom put to practice. Identified challenges of MSW management include poor funding/policy implementation/public awareness, inadequate and or obsolete infrastructure, lack of trained personnel/waste mangers, non-existence/pitiable recycling and recovery facilities, insufficient sanitary laws/ineffective enforcement of enacted sanitary laws, etc. Generated MSW across the country has demonstrated potential for waste-to-energy conversions, economic viability in term of revenue generation and job creation given the needed commitment. The paper recommends wide-ranging measures for overcoming the menace.

Key words: Municipal solid waste, waste management practices, public health, energy potential

1. Introduction :

Solid waste could be describe as any discarded substance or object by its owner as reported by Jane *et al*., (2017), while Festus and Omoboye (2015) stated that wastes are materials or substances that are either spoiled, rejected or no longer required for their original purpose. Thus, this implies that leftovers or redundant substances or materials could be classified as waste. It is a common practice seeing persons on dumpsites in Nigeria for materials that could be put into use or resold. This has brought into limelight if wastes are actually of no value or unwanted materials. In general, waste could in any three of the states of matter namely solid, liquid or gas. Common terms like garbage, trash, refuse, and rubbish are often used in describing wastes in solid form.

Nigeria is located on the western coast of Africa, and bordered to the north by Niger republic, to the east by Chad republic and Cameroon republic, to the south by the Gulf of Guinea of the Atlantic Ocean, and to the west by Benin Republic. The country experienced tropical climate with variable rainy and dry seasons. Currently, it is the most populous country on the Africa continent and constitutes about 2.78% of the total world population. Basically, the country is divided into two major divisions of north and south base on marked differences not only in physical landscape, climate, and vegetation but also in the social life, religion, literacy, and agricultural practices. The southern region is more economically advance and home to most of the country's industrial towns and cities. On the political scale, Nigeria is divided into 36 units called states for easy administration with each state having a town as its headquarters with further subdivision of states into units called local government areas for grassroots administrative purposes. Presence of educational institutions, companies, administrative offices, tertiary health facilities and social amenities have attracted the working class especially youths and other form of workers to state and local government areas headquarters inclusive of other major towns in the country. This population explosion has consequently increased the rate of municipal solid waste generation in the cities and towns. Studies have shown that MSW collection and delivery services have fell to meet generation rates of MSW in most urban areas in the country thus, becoming a menace to public health. Ogbonna *et al* (2002) have observed that little or no attention is given to some traditional suburban settlements for provision of waste collection and disposal services. As a results, there are reported cases of wastes are been seen littered on streets/major roads in towns and cities, dumped in water bodies, burn in open spaces among others.

This review paper attempts to develop a further scale of knowledge base on facts on municipal solid waste generation not from a particular district or area but a total coverage of the country by expansively reviewing the accessible previous empirical works and evaluating the information to ascertain the rates of municipal solid waste generated in Nigerian towns and cities, its energy potential, economic viability, management methods, challenges and then provide possible recommendations to those in charge of policy making and implementation as well as environmental management to proficiently salvage Nigeria from the menace.

2. Methodology :

Previous research empirical works relevant to municipal solid waste (MSW) generation, management practices and challenges and waste-to-energy potentials were accessed and evaluated across the country focusing prominently on commercial towns, administrator headquarters and cultural centres for expansive and elaborate understanding of municipal solid waste in Nigeria. The review was carried out in two sections namely: those in the northern part of the country and in the southern Nigeria. The Northern-Nigeria consists of 19 states from three geo-political zones of North-Central, North-East and North-West with 6, 6 and 7 states respectively and Abuja being the Federal Capital Territory (Administrative Headquarter of the country), while the Southern-Nigeria is made of 17 states from three geo-political zones of South-South, South-East and South-West of 6, 5 and 6 states respectively

(Figure 1)

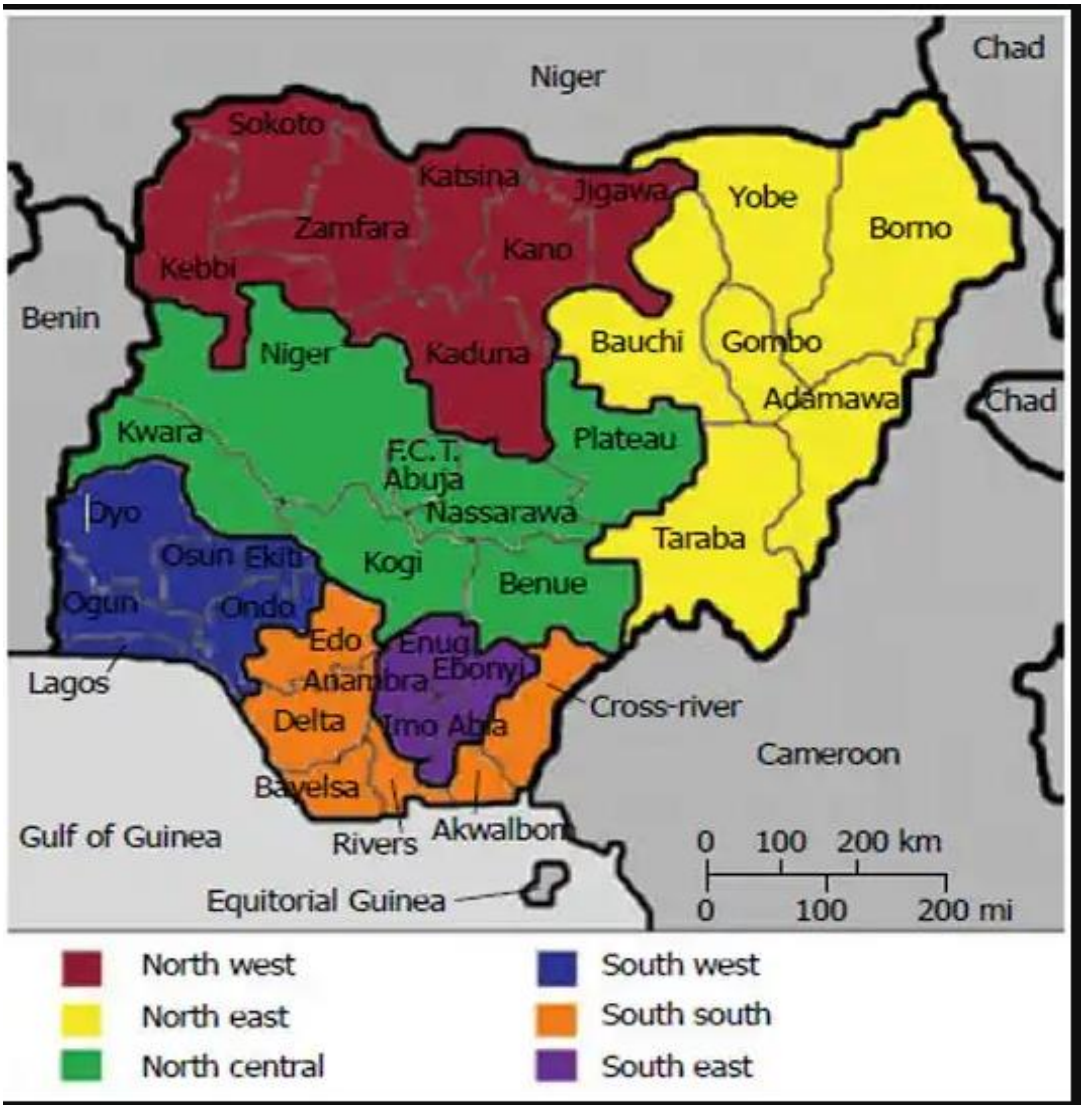

Figure 1: Map of Nigeria showing the geo-political zones and the 36 states of the Federation (GIS, Nigeria 2023)

3. Types of Municipal Solid Wastes (MSW) :

As asserted by Adamu *et al.,* (2019), the Environment Protection Authority (EPA, 2014) has reported to have classified waste into the following categories namely:

3.1 Hazardous and Non-hazardous Waste

These are waste materials that have the tendency or potential to cause impairment. They are found to have the following characteristics; flammable, poisonous, corrosive, reactive and contagious. Those not found to be detrimental, hurtful, dangerous, injurious, damaging, risky and the all like types are classified as non-hazardous wastes.

3.2 Liquid waste

All sources of waste water from industrial plants, flood water, human waste, silage and other forms of terminated water is known as liquid waste. Human wastes consist of sewage, sewage sludge, black water and all that contain human feces. Excreta generally comprise of urine and feces. Human body waste is categorized as liquid waste and mixture of human waste with waste water is known as sewage also called black water. Runoff water occurs when the land is saturated and can no longer absorb water. The excess water then flows on the land surface into nearby streams, ponds or rivers. This process could be natural phenomena or facilitated by human activities or both.

3.3 Solid waste

Unwanted solid materials disposed by individuals in a dry form are called solid waste. These materials could originate from households, educational institutions, commercial centre's, government offices, privates offices, agricultural waste, street among others. Waste from kitchens in the solid form in the course of food preparation or foodstuff leftover after eating is called garbage.

4. Classification of Municipal Solid Waste (MSW) Base On Land Use :

Municipal solid waste (MSW) could be categorized into various classes base on land use. These include the following;

4.1 Garbage

These are household waste and consist of leftover food, fruits, vegetable peels, fallen leaves of potted plants, waste paper, unwanted plastic and glass objects, meats and wooden objects, rags, discarded shoes, clothes etc. Inclusive are containers containing rotting organic matter with offensive odour.

4.2 Ashes and Residues

Ashe residues are a composition of substances resulting from the combustion of solid waste or a solid waste in combination with fossil fuel in a solid waste incinerator. These include bottom ash, boiler ash, fly ash, and the solid residue of any air pollution control device used at a solid waste. This includes all solid substances remaining from burning of combustible materials for cooking and heating in households, institutions, commercial centres etc.

4.3 Combustible and non-combustible waste

A non-combustible substance is a material that neither burns nor gives off flammable vapours in sufficient quantity for self-ignition. Any other material is a combustible material. Examples of combustibles are paper, cardboard, textile, rubber, glass, crockery, aluminum cans.

4.4 Bulky waste

This is a term used in waste management in describing various wastes that are large to be accepted by regular waste. Examples are vehicle parts, tyres, discarded furniture such as couches, tables, recliners, washing machines, big appliances (refrigerators, ovens, Televisions), plumbing fixture (bathtub, toilets, sinks), crates.

4.5 Street waste

Waste materials originating from soil material collected through various routine highway maintenance activities such as street sweeping, ditch cleaning (ditching), and cleaning out catch basins and other storm-water management infrastructures. Examples of such waste include paper, cardboard, plastic, dirt, dust, leaves and other vegetable matter.

4.6 Biodegradable and non-biodegradable waste

Biodegradable waste refers to materials that can be decomposed naturally by microorganisms and other living organisms, while non-biodegradable materials cannot be decomposed naturally by any living organisms. Examples of biodegradable waste materials are food waste, .human waste, manure, sewage sludge, abattoir waste, dead animals and plants, hospital waste, etc.

4.7 Construction and demolition waste

Construction and demolition (C&D) waste is generated from construction, renovation, repair, and demolition of houses, large building structures, roads, bridges, piers, and dams. C&D waste is made up of lumber, steel, concrete, gypsum, roofing, plumbing materials, masonry, plaster, metal, and asphalt.

5. Sources of Municipal Solid Wastes (MSW)

5.1 Municipal

These are waste originating from street sweepings, debris from construction and demolition works inclusive of landscaping activities. It could also include deserted vehicles.

5.2 Residential

Refuse from households apartments and other places of dwellings for humans constitute residential wastes. Examples include food leftovers, papers, clothing, vegetable peels, containers for packaging foods such as plastics, cans, bottles, glass etc.

5.3 Commercial establishments

Structures where commercial activities are carried out are centres for generating wastes such as stores, office buildings, restaurants, parks. Waste materials found in such areas are paper and cardboard, glass, plastics, packaging waste, organic waste, yard waste, hazardous waste and bulky waste.

5.4 Institutions

Centres of learning (pre-primary, primary, colleges and tertiary institutions), health centers (both primary and tertiary) and buildings where government administrative functions are executed constituent institutions. Examples are paper and cardboard, glass, plastics, packaging waste, organic waste, yard waste.

5.5 Agricultural sources

Wastes emanating from the activities of man, crops and crop tress planted which later form residues constitute agricultural wastes. These comprise of farm orchards, open and close fields, vineyards and farms. Waste as a result of agricultural activities such as planting and harvesting of crops, grazing, meat/milk production among others.

5.6 Industrial

Waste produced from a wide range of activities involved in companies for the production of goods. Examples are process waste, ash, demolition and construction waste, smoke.

5.7 Open sources

Waste from streets, alleys, parks, vacant and parking lots, playgrounds, beaches and highway.

6. Review of Relevant Literature for Northern-Nigeria Region

Akpen and Aondoakaa (2009) determined solid waste generation rate by using household approach subjected to statistical analysis of ANOVA and Chi-Square tests for Gboko town. Results showed significant variation in composition which could be a source of raw material in organic fertilizer blending plants with average generation put at 0.45kg/person/day. Chukwunonye (2010) in his analysis of MSW sample data collected in Abuja indicated that 65-70% are biodegradable mostly comprising of high wet weight and high moisture content kitchen wastes, while between 11%-30% of the MSW sample from the city town was made of non-degradable but recyclable materials. He attributed major challenge to MSW sustainability management to include low public awareness/education, obsolete and insufficient equipment and funding limitations. Ogwueleka and Ogwueleka (2010) applied artificial neural network on energy modeling needs in Abuja for predicting municipal solid waste values. Lower heating values had strong relationship with plastic, paper, glass, textile and food. The artificial neural network produced results with average percentage error less than 9.13% and 9.4% for training and validating dataset respectively when compared to measured data. Aliyu (2010) undertook a municipal solid waste

analysis in Kano metropolis by means of secondary data, interviews and field surveys. Kano metropolis's is found to generate solid waste consisting of organic and other biodegradable matter that accounts for 43% and constitutes 68.26% by weight of solid waste. Oyeniyi (2011) adopted a sociological approach to examine waste management in contemporary Nigeria via a case Abuja. Findings indicated solid waste management has overwhelmed the Nigerian government. Ityona *et al.,* (2012) evaluated the generation, characteristics and energy potential of municipal solid waste for power generation in Nigeria. MSW samples were obtained randomly from different dump sites in selected state capitals, at least one from each of the six geopolitical zones based on the spot sampling method of Corbit. An average calorific value of 17.23 MJ/kg with variable high water content of 20- 49% was determined for MSW using a bomb calorimeter and on the basis of an incineration plant of capacity 1500 ton of MSW/day, 700kW/day of power could be generated. Oumarou *et al.,* (2012) focused on the characterization and generation of municipal solid waste in the north central part of Nigeria through daily sample collection across the seasons and interpretation of data via microsoft excel. Wood, paper, plastic and leaves were found in varying proportions and with average waste generation of 1.23 kg/person/ day. Jonathan (2013) assessed the application of Geographic Information Systems (GIS) in evaluating spatial location of solid waste dump sites and collection scheduling in Bauchi metropolis. Study data obtained on household reveal an average household size of 9 and daily solid waste generation of 6.11kg/household/day, and 0.80kg/ person/day. Kadafa *et al.,* (2013) aimed at identifying current municipal solid waste management status for Abuja using integrative approach. Based on the findings, they concluded that municipal solid waste management is a serious issue due to its negative impact on human health and environmental sustainability. Ejaro and Jiya (2013) employed the method of source specific quantification and characterized municipal solid waste generated in Lapai. Study reveals food waste with 20%, polythene and plastics had 16%, while wood/saw pieces was 2%. Bichi and Amatobi (2013) characterized municipal solid waste generated in Sabon-gari, Kano City by dividing the area into three zones. It was found that 57.5% of the solid waste generated was made up of food/petruscible matter and vegetable matter; 17.6% plastics and 3.0% metals, whereas per capita waste was 0.31kg/capita/day. Muhammad and Manu (2013) assessed roles of informal solid waste management issues in Kaduna. The result shows 55% of recyclables are being sold by women, 40% by children and 5% by men. Benjamin *et al.,* (2014) presented municipal solid waste characterization in the Federal Capital Territory, Abuja. It was found that major waste generated was food/petrucsible whilst waste generation ranged between 0.59 to 0.79kg/capita/day. The state owned waste management agency, Abuja Environmental Protection Board, AEPB is faced with constraints such as inadequate institutional framework/budgetary provision/by-laws and regulations. Adamu *et al.,* (2014) investigated the missing-link between sustainable solid waste management in Bauchi metropolis by adopting cluster random sampling via questionnaires. Results from data analysis indicated insufficient and misappropriation of funds, open dumping and obsolete equipments are key challenges for solid waste management. Ogah *et al.,* (2014) stated that effective management of municipal solid waste is more challenging in high density areas than in the medium and low, a case study of lafia. Their study was based on the data gathered through administration of questionnaire using systematic sampling method. Butu and Mshelia (2014) assessed municipal solid waste disposal methods and the environmental issues associated with its management in Kano metropolis. Results findings through primary data and interviews clearly shows that major streets, open spaces and water ways are used as refuse dump sites, while the composition of the waste was heterogeneous. Adeniyi (2014) highlighted the existing solid waste management structure in Samaru, Zaria via primary and secondary sources of data. The result point out that the state agencies in charge of solid waste management are deficient due to inadequate funding, infrastructure, trained personnel, etc. Ogah *et al.,* (2014) described the socio-economic characteristics of households, types of waste generated and methods of disposal in Lafia by means of systematic sampling method. They deduced that the major types of municipal solid waste are generated in all areas, and quite a number of households use either plastic or metal buckets for collection and disposal of waste. Gwom *et al.,* (2014) reviewed municipal solid waste management in Jos by means of literature, in-depth interviews, participant observations and questionnaire. Unfavourable economic, financial, institutional, legislative, technical, operational and socio-cultural constraints were known to affect municipal solid waste management. Aguoru and Alu (2015) carried out studies on the waste disposal and management practices in Makurdi metropolis and its environs utilizing face to face structured interviews, visitations, observations and review of secondary data. Though, waste containers were found in households/shops disposal methods were questionable as wastes were littered on streets, gutters, undeveloped plots, or dumped into rivers and streams. Ben *et al.,* (2016) presented results of municipal solid waste samples collected for a duration of three years across all season in selected major cities of the north western Nigeria. Calorific values of wastes were found not appropriate for electricity generation. Mudiare *et al.,* (2016) observed key players involved in the management of solid wastes in Tunga to be government and individual households, while rate of waste generation exceeded rate of waste disposal using both primary and secondary data. Ben *et al.,* (2016) developed a statistical linear regression mathematical model for predicting energy content in municipal solid wastes for cities of Kano, Katsina, Dutse, Damaturu, Maiduguri, Bauchi, Birnin Kebbi, Gusau and Sokoto. Experimental and predicted calorific values had agreement of about 70% and deviation of 5.03%. Maton *et al.,* (2016) adopted Survey tools of literature review, questionnaires, oral interviews/focus group discussions and observations in identifying waste management challenges in Jabi district of Abuja to include non-sorting and bagging of waste at collection stage, inadequate infrastructure, ineffective enforcement of environmental regulations, etc. Salamatu and Safianu (2017) reported the characterization and composition analysis of MSW in Kano metropolis. Solid waste samples were collected and analyzed from four major dumpsites during the dry season. There was significant correlation between estimated population and volume of waste collected. Janet (2017) studied current waste management system in Jos with major focus on low income areas via the use of mixed methods. Existing waste management system was found to be grossly inadequate. Residents disposed waste through open dumping/burning and water bodies causing negative impact on the public health. Challenges identified included inadequacy of resources; political meddling, poor governance and infrastructure, inefficiencies in government agencies and lack of waste awareness amongst the public. Nelson *et al.,* (2017) used quantitative approach for data collection, stratified random sampling and descriptive statistics to analyze the perception and benefit of recycling solid waste in Kaduna metropolis. Low income households are said to recycle waste compare to high income households, while correlation shows three basic recycling habits of disposal, segregation and information gathering. Research study also visualizes four elements of perceptions: environmental preservation, resources and cost conservation, monetary reward and environmental awareness. Kaoje *et al.,* (2017) conducted a descriptive cross-section survey to determine the residents' perception about waste disposal in Sokoto metropolis using a two stage sampling technique. The investigation shows more than 90% of participants expressing worries about indiscriminate littering of the metropolis. Ahmed and Onyidoh (2018) administered questionnaires randomly to residential, institutional and industrial areas to evaluated municipal solid waste disposal practices and its challenges in Zaria and Kaduna metropolitan areas. Refuse dumps and incineration options were mainly advocated

with recycling as the best control measure. Gabriel and Bawagana (2018) critically examined the problems of solid waste disposal and management in Ramat Polytechnic Maiduguri. The results obtained indicated that food wastes, polythene bags and polystyrene food packs constituted largest component of wastes in hostel area with disposal methods of waste bins/receptacles and open surface dumping mostly practiced. Emankhu and Yamusa (2018) focused on municipal solid waste from the perspective of household waste management system in Lafia. Questionnaires randomly distributed to households in eight communities gave average waste generation per household as 0.65kg/capita/day with biodegradable material constituting 67.6%, and 32.4% recyclables. Oruonye *et al.,* (2019) described the influence of environmental education on solid waste management in Karu metropolis via four research questions using standard research instrument of questionnaire. Key result findings disclose high level influence of environmental education on peoples' attitude toward waste collection, disposal and management. David *et al.,* (2020) reveal that organic wastes, nylons and plastics form bulk of MSW generated, open dumping the most practiced method of waste disposal, while activities of government agencies in waste management have not yielded substantial result in waste management in Nasarawa LGA of Kano. Oloche *et al.,* (2020) ascertained average per capita generation rate of 0.45kg/capita/day for MSW in Makurdi metropolis from three selected (3) residential areas (low/medium/high income) using field observations, secondary data and key informant interviews. Key waste components were organic, ash/sand, paper, metal/tin, bag/shoes, leather, textiles, plastic and glass/ceramics. Charles *et al.,* (2023) explored energy production from organic fraction of municipal solid waste, OFMSW in the thirty-six state capitals and Federal Capital Territory (FCT), Abuja. Daily OFMSW generation ranged from 10416 tons per year (TPY) in Damaturu, to 1.6 million TPY in Lagos with annual estimate at about 4.7 million tons per year (TPY). Estimated 1.82 billion Nm^3 of biogas could be obtained from anaerobic digestion (AD) of OFMSW generated in the cities annually, about 984 Gg (1085688 tons) of methane recover from landfill gas technology, while drying and densification will produce about 1.82 million tons of solid fuel. Danjuma and Samaila (2023) predicted waste-to-wealth values chain and energy saving from waste management in North-East Nigeria via application of Waste Reduction Model (WARM-Model). Data analyzes using econometric software and Microsoft Excel for estimating waste generated, energy saved and profitability of waste management in the most waste generating North-Eastern states of Bauchi, Borno and Adamawa unveils huge amount of wealth from trading various recyclable waste materials and energy saved via WARM-Model application.

7. Review of Relevant Literature for Southern-Nigeria Region

Ibiyemi (2008) evaluated economics of solid waste management in Lagos state using 50 manufacturing firms, and activities of 100 randomly selected scavengers. The Chi-square Goodness-of-Fit test reveal that less than 20% of the solid wastes generated is recovered. Recycling credits, product charge and tax concessions were some recommendations for stimulating waste generators in seeking out least cost combination of for disposal, recycling and reuse. Oyelola and Babatunde (2008) estimated the seasonal composition of household and market wastes generated during a period of 48 days. The seasonal composition shows a high generation of putrescible during the wet season and nylon during the dry season. Babayemi and Dauda (2009) assessed the efficiency of solid waste generation rate and management in Abeokuta using structured questionnaire. Results points to large generation at high rate without a corresponding efficient technology in managing the wastes. In furtherance, 35.8% used waste collection services, 64.2% other disposal options, 16.4% used both, 68.7% and 58.7% aware of waste collection service and management regulations respectively, while 28.4% separated their solid wastes at source. Kayode and Omole (2011) adopted survey design method in Ibadan metropolis to appraise the socio-economic factors affecting solid waste generation and disposal. Field data analysis shows socio-economic factors of income, age, education, occupation and building types as key factors affecting waste disposal method. Ye-Obong and Uduak (2013) recommends proper MSW management for improved air quality and minimum health hazards. The study also indicated a daily delivery of 2,714 tons of waste in a city which could be use for generating about 30 to 52 MWh of electricity. Ibrahim *et al.,* (2014) used descriptive and inferential statistics to analyzed data collected in three residential density areas of Lagos megacity for evaluating performance of public private partnership in household solid waste management. Household average solid waste generation per week ranges between 22.75kg in the medium residential density area and 30.39kg in the high residential density region with estimated per capita waste at 0.95kg/day. Regression models suggested that the public private partnership performance was significantly influenced by economic status, affordability, flexibility, consistency, cleanliness, coverage and accessibility, number of waste collection vehicles, vehicle maintenance, capacity, trip rate, frequency, number of personnel and quality of personnel. Michael *et al.,* (2014) highlighted waste-pickers activities and composition of solid wastes based on literature and field survey at Awotan Solid Wastes Dump Site (ASWDS). They suggested that waste-pickers and their organizations could be integrated into solid waste management system, while effort should be made to provide basic and affordable education to their children. Also, land-fills should be design to enable safe rummage by waste-pickers through garbage before it is deposited and buried. Agboje *et al.,* (2014) evaluated the performance of solid waste management through private partnership in Lagos state. Quality of service provided by the private partnership operators is highly successful in high income areas as against medium and low income areas. Olalere *et al.,* (2014) studied different practices and technologies for managing wastes generated in food processing companies in the state of Oyo and Lagos using structured and unstructured questionnaires. Food/raw wastes ranked highest among varied types of solid waste generated, 5000 to 10,000 litres volume of wastewater were generated per company per production activity, peeling and cutting operations ranked highest among different sources of wastes generation, while open dumping/land filling and contracting of waste for disposal were the major waste management disposal practices. Iyanda and Olaniyi (2014) identified various municipal waste disposal methods mostly practiced in South Sahara region using Ibadan, the third largest city of Africa as a case study. Questionnaires were administered to households in all wards of Ibadan. The rating results from the survey reveal that the most practiced municipal waste disposal method was open burning. Oloruntade, *et al.,* (2014) presented the various steps and approaches taken in Akure to combat MSW menace. These approaches included creation of special agencies for waste collection, recycling and conversion; recruitment of Sanitary Inspectors and Volunteer Youth Corps; awareness campaigns and collaboration with other government agencies are said to have improved compliance with sanitary laws and helped in effective municipal solid waste management. Onwuemele and Andrew (2015) analyzed the determinants of solid waste generation and disposal systems in Benin City utilizing simple survey design covering six randomly selected neighborhoods. Using descriptive and inferential statistics for data obtained, study reveals that the quantity of waste generated as well as solid waste disposal methods among households was a reflection of the variation in the socio-economic status of the people. Olayinka *et al.,* (2015) described the inter-relationship between household's

solid waste generation and disposal in selected slum areas of Lagos State via primary and secondary sources of data with a multi-stage sampling technique. The study deduced that 36.6% houses far from dumpsites have high rental value and high household's number which often gives greater quantity of solid waste generated and disposed. Josephine and Caleb (2015) conducted waste management practices study in selected hospitals in densely populated regions of Ondo state. Average medical waste generation rates were 0.676kg/bed/day and 2.51kg/bed/ward/day. Audu *et al.,* (2015) investigated the composition of municipal solid waste in Port Harcourt local government area according to ASTM D5231-92 (2008) Standard Test Method using five distinct communities. Variations in waste composition existed across locations prominently organics, paper and nylon with mean percentage compositions of 65%, 13% and 12% respectively with generation rate of 1.16kg/cap/day. David and Myem (2015) undertook a study of rate of solid waste generation in Ado-Odo Ota local government. Quantitative and qualitative techniques in data collection and analysis were utilized as research instruments. Results show that municipal solid wastes generated constituted 38.49% biodegradable and 61.51% non-biodegradable materials. Igbinomwanhia *et al.,* (2016) presented waste-to-energy potentials of domestic solid waste in Benin metropolis using a three-phase study plan of; current waste management activities, characterization and determination of waste-to-energy potentials. The outcome reveals that about 13.18% of combustible solid waste is generated within the metropolis having an average calorific value of 20,198.89 kJ/kg producing energy value of 36.95 MW/day. Adejumo *et al.,* (2016) evaluated the perceived effect of waste generation on climate change among rural households in Oyo state using five villages each randomly selected from two local government areas from the three senatorial districts. Interview schedule data was descriptively analyzed, while Pearson Product Moment Correlation and Chi- Square were used for inferential analysis. Kitchen waste, crop waste and animal waste were the major waste generated within the households with major waste disposal methods by the use of sacks, drainage channels and flowing stream. Odoemene and Ofodu (2016) aimed at proposing an effective solid waste management practice and inclusiveness at evaluating cleaner form of energy from solid wastes issued questionnaires to traders, non-traders and Abia State Environmental Protection Agency (ASEPA) workers as well as collection of solid waste samples from landfills, markets and dustbins in Aba metropolis for proximate analysis. Findings reveal low awareness on reuse, recycling and energy recovery with agreement that behavioral pattern helps to improve solid waste management practice. Heating value from waste sample was above the standard required for waste to energy generation. Timiebi and Anthony (2017) examined the current waste management practice in Port Harcourt through personal observation and previous research materials. It was found that, wastes are often burned or disposed off on landfills, open dumps and water bodies without prior treatment. Eze-Ilochi and Oti (2017) investigated the biomass properties of bambara nut shell, bush mango nut shell, cassava stalk, cocoyam peel, detar shell, empty fruit bunch, maize stalk, mango seed shell, sugarcane bagasse, and wild cassava peel in comparison to coal for application in bio-fuel production. Low sulphur, ash content as well as low concentration of the metals in the biomasses presented them as a better fuel than coal. Edward *et al.,* (2017) empirically evaluated monetary and economic significance of solid waste management through two formulated hypotheses in Anambra. Generated data was tested with Z-test statistic using descriptive analysis and indicated that large percentage of respondents agreed significantly that solid waste management affects internally generated revenue and youth employment. Olugbenga *et al.,* (2018) characterized and determined the recycling potential of municipal solid waste in Akure from three sources namely market, residential and curbsides. Statistically significant differences exist in all the types of waste except paper. Chemical conditions of organic waste showed it could be used for efficient composting. Boye and Olusegun (2018) described the relationship between waste management logistics and challenges inhibiting smooth performance of the Lagos State Waste Management Authority (LAWMA). Questionnaires were randomly distributed per centre across the 20 Local Government Areas (LGA). The results established that the volume of solid waste and commitment of staff are crucial to waste management logistics as well as metropolitan traffic which strongly affect waste logistics. Obiora *et al*., (2019) obtained for Awka municipal solid waste similar to other Nigerian towns with organic (73.2%), plastic (8.0%), and recyclable (20.3%). Waste generation rate was 416.9 g/capita/day, 307.1g/capita/day for organic waste generation, recyclable waste generation rate was 83.0 g/capita/day, paper and textile waste generation rate was estimated to be 25.2 g/capita/day, loose waste volume rate was put at 9.02×10^{-1} dm^3 /capita/day, and compact waste volume rate 4.51×10^{-1} dm^3 /capita/day. Emri *et al.,* (2019) investigated solid waste collection and management in Calabar South through the use of questionnaires randomly distributed to residents in the twelve (12) wards of the Local Government Area. Findings show inadequacy of waste bins at waste disposal designated locations. Nkwocha *et al.,* (2023) adopted a mixed-method approach of qualitative and quantitative research in Aba for waste management. Inadequate waste collection, and public awareness, poor funding/disposal infrastructure were some of the key challenges identified.

Plate 1: Ijesha Road, Ikeja, Lagos State (Author: 22nd August, 2023)

8. Results and Discussions

The amount and rate at which solid waste is generated across Nigeria varies as it's a function of certain factors which include but not limited to the population density of location, presence of industries, economic status and purchasing power of the citizenry. The review have demonstrated potential for waste generation per person per day as follows: Gboko in Benue state (0.45kg/person/day) (Akpen and Aondoakaa, 2009), north central Nigeria (1.23kg/person/day) (Oumarou *et al.,* 2012), Bauchi in Bauchi state (0.80kg/person/day) (Jonathan, 2013), Sabon-gari in Kano state (0.31kg/person/day) (Bichi and Amatobi, 2013), Lagos megacity in Lagos state (0.95kg/person/day) (Ibrahim *et al.,* 2014), Federal Capital Territory, Abuja (0.59 to 0.79 kg/capita/day) (Benjamin *et al.,* 2014), Ogbomosho in Ado-Ekiti (0.95kg/person/day) (Charles, 2015), Port Harcourt in Rivers state (1.16kg/person/day) (Audu *et al.,* 2015), Lafia in Nasarawa state (0.65kg/person/day) (Emankhu and Yamusa, 2018), Akwa in Anambra state (0.42kg/person/day) (Obiora *et al*., 2019), Makurdi in Benue state (0.45kg/person/day) (Oloche *et al*., 2020). On the basis of waste-to-energy, some works have shown some potential for energy production. Ityona *et al.,* (2012) stated that on the basis of MSW collected from some state capitals, an incineration plant of capacity 1500 ton of MSW/day could generate 700kW/day of power. Ye-Obong and Uduak (2013) indicated that from a daily delivery of 2,714 tons of waste in one city in southern-Nigeria, about 30 to 52 MWh of electricity can be generated. A research work on waste conducted in Benin metropolis on waste-to-energy potentials of domestic solid waste by Igbinomwanhia *et al.,* (2016) has an average calorific value of 20,198.89 kJ/kg producing energy value of 36.95 MW/day. Odoemene and Ofodu (2016) used Dulong modified formula to obtain heating value from waste samples in Abia state which gave between 22871-24457kJ/Kg which is above the minimum required for waste to energy generation. Ibikunle *et al.,* (2019) reported the energy potential of waste streams available for energy production in Ilorin metropolis, Kwara state based on the energy content of 584 tons/day of MSW to be 3,244 MWh, Electrical Power (EPPMSW) of about 41 MW and Power to Grid of 27 MW. Chukwuebuka *et al.,* (2022) gave an estimate of 20378 tons of MSW each day from 34 million populations living in the cities with energy potential put at about 947981358 kWh/ year, revenue potential of $131769409 and trading/recycling MSW benefits ranged from $493.3 million to $16.4 billion. Charles *et al.,* (2023) have reported a daily organic fraction of municipal solid waste (OFMSW) generation between 10416 tons per year (TPY) in Damaturu, to 1.6 million TPY in Lagos with annual estimate at about 4.7 million tons per year (TPY) with a biogas projection of about 1.82 billion Nm^3 from anaerobic digestion (AD) of OFMSW generation in the cities each year, while about 984 Gg (1085688 tons) of methane recovery from landfill gas technology. The work reveal that MSW management practice techniques are prominently open dumping, landfill, open burning, street/stream/river dumping, while incineration method is seldom put to practice. Problems associated with Municipal Solid Waste, MSW management service delivery include poor funding/ policy implementation/public awareness, inadequate and or obsolete infrastructure, lack of trained personnel/waste mangers, non-existence/pitiable recycling and recovery facilities, insufficient sanitary laws/ineffective enforcement of enacted sanitary laws, etc.

9. Conclusions and Recommendations

Urban centers are the greatest source of Municipal Solid Waste, MSW and hence, experienced high level of pollution causing menace to public health, decrease in economic productivity and negatively impacting on the ecosystem. Currently, the three tiers of government (federal, state and local governments) are overwhelmed by the huge amount of waste produced daily across cities and towns in the country. However, with commitment from the government or in partnership with private sectors investors, viable and adequate power could be generated throughout the year base on data available for daily municipal waste production. This will make more availability of power for commercial and household activities, promote cleaner environment and thus higher economic productivity, give more revenue to the government and create more jobs for the citizenry. Consented efforts must be made to achieve effectiveness in the management of municipal solid waste. Poor budgeting allocation of government owned waste management agencies, trained and re-training of personnel, enactment and effective enforcement of sanitary laws, establishment of waste treatment/recycling plants, aggressive implementation of waste-to-energy conversion technologies, public educational enlightenment programmes on waste disposal, public/private partnership must be pursue by all tiers of government in order to overcome the menace of municipal solid waste in Nigeria.

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