The Optimization of Municipal Solid Waste as a Potential Energy source for Power Generation and Sustainable Development in Nigeria

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THE OPTIMIZATION OF MUNICIPAL SOLID WASTE AS A POTENTIAL ENERGY SOURCE FOR POWER GENERATION AND SUSTAINABLE DEVELOPMENT IN NIGERIA

A OTIMIZAÇÃO DE RESÍDUOS SÓLIDOS MUNICIPAIS COMO FONTE POTENCIAL PARA GERAÇÃO DE ENERGIA E DESENVOLVIMENTO SUSTENTÁVEL NA NIGÉRIA

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*“If you really think the environment is less important than the economy,
try holding your breath while you count your money”*

------ Dr Guy McPherson

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Resumo

A Nigéria, com uma população em crescimento de mais de 188 milhões de pessoas encontra-se sobre uma pressão tremenda no meio ambiente relacionada com o fornecimento de energia elétrica assim como com a gestão de resíduos sólidos urbanos (RSU). O rápido crescimento populacional, a urbanização, a industrialização e a mudança no estilo de vida tem contribuído largamente para a grande procura de eletricidade assim como para um grande aceleramento do ritmo de geração de resíduos sólidos urbanos. Além disto, a indisciplina ambiental, as práticas de gestão insuficientes das autoridades, apesar das políticas ambientais existentes que não são as mais adequadas devido à sua reduzida implementação e à inexistência de fiscalização resulta na deposição de resíduos em locais não controlados nas maiores cidades da Nigéria. Estes problemas causam muitos riscos de saúde humana e um declínio no crescimento económico da nação, poluição ambiental e mudanças climáticas, em geral. Em reposta às crescentes preocupações o défice de energia e a gestão inadequada dos RSU, alguns cidadãos com condições económicas utilizam a energia renovável (solar) assim como um gerador (gasóleo ou gasolina) para obter energia elétrica. No entanto, o descarte inadequado de RSU é ainda uma prática comum na periferia de Abuja contando com uma produção diária de 0.76 kg/pessoa. Este estudo pretende investigar os RSU como uma fonte complementar e potencial para a produção de energia elétrica e a sua distribuição em Abuja, Nigéria. A abordagem adotada para atingir o objetivo deste estudo foi: desenvolver uma estrutura conceitual sobre educação e divulgar os pontos fortes da gestão de resíduos e da ética ambiental; desenvolver uma metodologia para a monitorização e gestão de RSU através da combinação de técnicas geo-espaciais com tecnologia e dados coletados no local; definir os locais mais adequados para a construção de um aterro sanitário ambientalmente sustentável de acordo com as diretrizes existentes; investigar a produção de resíduos sólidos atual; caraterização; e atuais práticas de gestão de resíduos em (AMAC e Bwari LGA) Abuja, Nigéria; avaliar os potenciais caloríficos dos fluxos de RSU através de analises químicas, física e elementares; e uma analise comparativa, utilizada para estabelecer uma possível relação do potencial de geração elétrica de RSU entre Abuja (Nigéria) e o Porto (Portugal) As metodologias utilizadas neste estudo foram: a conceção de um quadro como ferramenta de trabalho para o programa de divulgação e educação sobre gestão de resíduos e ética ambiental, utilizando os influenciadores (iniciadores) através de canais e procedimentos eficazes para as pessoas (destinatários); a utilização combinada de componentes geo-espaciais (Sistemas de Informação Geográfica (SIG), sensoriamento remoto

e Sistema de Posicionamento Global (GPS)) e Tecnologia de Comunicação de Informação (TCI) que inclui Identificação por Radiofrequência (RFID) e Serviços Gerais de Rádio por Pacote (GPRS). A integração de dados geo-espaciais: Landsat-7ETM+, NigeriaSat-X, ASTER-GDEM, mapas de base, mapas geológicos e de solo e avaliação multicritério (manual Ireland EPA, 2006), utilizados para formar mapas temáticos usando o potencial de analise espacial do software ArcGIS10.1 e o mapa de aptidão para aterro sanitário foi criado usando a análise de sobreposição ponderada do software ArcGIS 10.1. As análises físicas foram utilizadas para a caraterização de RSU nos maiores aterros e caixotes de lixo na área estudada (Abuja Nigéria e Porto Portugal). Além disso, analises elementares e fundamentais combinadas com a equação de Dulong modificada foram aplicadas para determinar os valores caloríficos de poder calorifico superior (PCI) e de poder calorifico inferior (PCS) para a determinação do potencial de recuperação de energia (prE) e o potencial de geração elétrico (PGE). Em adição, foi realizado um estudo comparativo do potencial de geração elétrico (PGE) dos RSU no Porto e em Abuja. Foram ainda comparadas a população geradora RSU em pesos equivalentes, com base na geração per capita diária em ambas as cidades. Espera-se que a estrutura conceitual sobre educação e divulgação provavelmente construa a percepção e a atitude da população sobre os benefícios da participação ativa na gestão de RSU. Além disso, a abordagem da integração de componentes geo-espaciais e componentes TCI vai muito provavelmente melhorar a eficiência de colheita e transporte dos RSU contribuindo para uma monitorização e gestão sustentável dos RSU. Por outro lado, foram identificadas 6 cidades como altamente adequadas para a instalação de aterros sanitários. No entanto, apenas quatro foram escolhidas devido à área terrestre dos locais selecionados e outras condições sustentáveis que não vão contra a utilização estabelecida para o solo em questão. Foi observado que os resíduos orgânicos/alimentares são produzidos em maiores quantidades, quando comparados com os restantes RSU. Os resultados das análises imediatas entre Abuja e Porto, mostram que o teor de humidade que os resíduos orgânicos sao (45,95%: 22,95%), para os plásticos é (2,38%; 2%), para o papel (42,90%; 16,39%), e para os têxteis é (8,79%; 1,50%), respetivamente. Adicionalmente, os resultados mostram que os valores caloríficos estimados dos RSU gerados no Porto e Abuja são PCS (3136.05 kcal/kg e 3515.80 kcal/kg) e PCI (3117.38 kcal/kg e 3495 kcal/kg) respetivamente. A partir dos resultados do PCI das áreas de estudo, o potencial estimado de geração de energia Qgp (Porto) e Qgp (Abuja) em intervalos de peso de 100 a 2000 toneladas mostrou que a relação entre o Qgp do Porto e de Abuja é de 1: 0,89. Além disso, descreve que a proporção da população que gera esses RSU em pesos equivalentes (Wt) gerados diariamente por pessoa para o Porto e Abuja é de 1: 1,71. Este estudo pode orientar o cenário de planeamento de projetos resíduos para com o fluxo de

RSU de Abuja e da Nigéria como um todo. Além disso, o estudo provavelmente ajudará na saúde publica dos Nigerianos, a estimar e a prever a energia a partir do fluxo de RSU na sociedade; e expandir a economia através da criação dum ramo alternativo no sector da energia.

Palavras-chave

Resíduos Sólidos Municipais, Lixão, Valores Caloríficos, Análise Próxima, Análise Final, Resíduos para Energia, Potencial de Geração de Energia.

Abstract

Nigeria, with a growing population of over 188 million people is under tremendous pressure on how to meet their electric power demand, as well as the management of municipal solid waste (MSW) in the environment. Rapid population growth, urbanization, industrialization, and changing lifestyle have contributed immensely to the high demand for electricity, and accelerating rate of MSW generation. In addition, environmental indiscipline, poor management practices by the authorities, despite the existing environmental policies which has failed due to their weak implementation and enforcement strategies has led to the indiscriminate dump sites found in Nigerian major cities. These problems have posed a lot of health risk to the people and has caused a decline in the economic growth of the nation, environmental pollution and climate change at large. In response to the growing concerns on the energy deficit and improper management of MSW, few citizens with good income status have turned to renewable energy (solar) and the use of a (diesel or gasoline) generator plant for their electricity supply. However, the indiscriminate dumping of MSW is still a problem to the Abuja environs with daily per capita generation of 0.76kg. On this note, this study aims to investigate on Municipal Solid Waste (MSW) as a complementary and potential fuel resource for electric power generation and distribution in Abuja, Nigeria. The approach taken to attain the aim of the study was to: develop a conceptual framework on education and outreach on waste management merits and environmental ethics; develop a methodology for MSW management and monitoring by integrating geo-spatial capabilities and techniques with existing ground-based data and technology; find the most suitable sites for a sanitary landfill facility for environmental sustainability with respect to the existing standard guidelines; investigate the present solid waste generation, characterization and current management practices in (AMAC and Bwari LGA), Abuja Nigeria; evaluate the calorific potentials of MSW streams using the (physical, chemical, and proximate) analysis; and a comparative analysis was used to establish possible relationship for the power generation potential of MSW in Abuja, Nigeria and Porto, Portugal. The methodologies adopted in the study were: the design of a framework as a working tool for outreach and education program on waste management and environmental ethics by using the influencers (initiators) through effective channels and procedures to the people (recipients); the combination of geospatial components (Geographic Information systems (GIS), remote sensing, and Global Positioning System (GPS)) and, (Information Communication Technology (ICT) which includes Radio Frequency Identification (RFID) and General Packet Radio Services (GPRS)); the integration of Geospatial data: Landsat-7ETM+, NigeriaSat-X, ASTER-GDEM, base map, soil and geology maps and multi-criteria evaluation (Ireland EPA) were formed into map layers by using the spatial analysis potential of the ArcGIS10.1 software and suitability map for sanitary landfill was created using the weighted overlay analysis of the ArcGIS10.1 software; The physical analysis was used for the characterization of the MSW at the major dumpsites / bins in study areas (Abuja Nigeria, and Porto Portugal. Furthermore, proximate and ultimate analyses in combination with the modified Dulong equation was employed to determine the calorific values Higher Heat Value(HHV or GCV), and the Lower Heat Value (LHV or NCV) in order to determine the Energy recovery potential (E_{rp}) and the power generation potential (P_{GP} or Q_{gp}). In addition, a comparison was carried out on the power generation potential (P_{GP} or Q_{gp}) of the MSW in Porto and Abuja. Furthermore, the population generating equivalent weights (Wt) of MSW based on per capita generation daily in both cities was also compared. It is expected that the conceptual framework on education and outreach is likely to build the perception and attitude of the populace on the benefits of active participation in the management of MSW. Also, the approach of integrating geospatial components and ICT components is likely to improve the level of operation in MSW collection and transportation for a sustainable MSW monitoring and management. On the other hand, six sites were identified as highly suitable for sanitary landfill facility. However, only four were preferred due to the land area of the identified sites, and other sustainable conditions with no intersection with sensitive land use. It was observed that food waste /organics have the highest percentage when compared to the rest of the MSW types. The result of the proximate analysis in the Abuja and Porto MSW show that food waste /organics clearly have a moisture content of (45.95%; 22.95%) likewise plastics (2.38%; 2%); paper (42.90%; 16.39%); textile (8.79%; 1.50%) respectively. In addition, the results showed that the calorific values estimated from the MSW generated in Porto and Abuja are HHV (3136.05 kcal/kg and 3515.80 kcal/kg), and LHV (3117.38 kcal/kg and 3495 kcal/kg) respectively. From the results of LHV of the study areas, the estimated power generation potential Qgp (Porto) and Qgp (Abuja) at weight intervals of 100 tons to 2000 tons showed that the ratio between the Qgp of Porto to Abuja is 1: 0.89. Also, it depicts that the ratio of the population generating these equivalent weights (Wt) of MSW at per person daily generation for Porto and Abuja is 1: 1.71. This study can guide the scope of planning Waste to Energy (WTE) projects with Abuja MSW stream and Nigeria at large. Besides, the study is likely to help in the sanitation of the Nigerian environment; estimate and predict energy from MSW stream in the society; and expand the economy by creating and alternative branch of the energy sector.

Key Words

Municipal Solid Waste, Dumpsite, Calorific Values, Proximate Analysis, Ultimate Analysis, Waste to Energy, Power Generation Potential.

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List of Acronyms

AMAC: Abuja Municipal Area Council.

ASTM: American Standard for Testing Methods.

CDM: Clean Development Mechanism.

DEM: Digital Elevation Model.

EC: Elemental Content.

ECN: Energy Commission of Nigeria.

EIA: Environmental Impact Assessment.

Erp: Energy Recovery Potential.

ESMAP: Energy Sector Management Assistance Program.

EU: European Union.

EV: Elemental Value.

FCT: Federal Capital Territory

FEPA: Federal Environmental Protection Act.

GCV: Gross Calorific Value.

GDP: Gross Domestic Product.

GIS: Geographic Information System.

HHV: Higher Heat Value.

IEA: International Energy Agency.

IPCC: Intergovernmental Panel on Climate Change.

IPMA: Instituto Português do Mar e da Atmosfera

IRBA: Integrated Risk Based Approach.

IWM: Integrated Waste Management.

IWMS: Integrated Waste Management Systems.

LGA: Local Government Area.

LHS: Latent Heat of Steam.

LHV: Lower Heat Value.

LULC: Land Use Land Cover.

MSW: Municipal Solid Waste.

NCV: Net Calorific Value.

NEPA: National Electrical Power Authority.

NERC: Nigerian Electricity Regulatory Commission.

NNPC: Nigeria National Petroleum Company.

P_{GP} (Q_{gp}): Power Generation Potential.

RE: Renewable Energy.

RDF: Refuse Derived Fuel.

RFID: Radio Frequency Identification.

RI: Risk Index.

SRTM: Shuttle Radar Topographic Mission.

UNFCCC: United Nations Framework Conference on Climate Change.

UNWSSD: United Nations World Summit on Sustainable Development.

USEPA: United States Environmental Protection Agency.

WCED: World Commission on Environment and Development.

Wt: Weight.

WTE: Waste to Energy.

Note: HHV = GCV; LHV = NCV; PGP = Qgp = Pgp

1.
General Introduction

1.1. Background of Study

Municipal Solid Waste (MSW) management is labeled as a major problem faced by most major cities in the world. With population growth and waste generation on the rise, there is need for an effective waste management response to combat the challenges of sustainable development if there's any chance of meeting current needs without jeopardizing the potentials and ability of future generations to meet theirs (WCED, 1987). Similarly, in Saheed et al. (2008), it was reported that the generation MSW is directly proportional to population, industrialization, urbanization and the changing lifestyle, food, habits and living standards of the people. Policy makers and scientific researchers have raised concerns on the challenges of MSW in developing countries because of its effect on public health and the environment at large (Aremu and Ritesh, 2016). A study by World Bank (2012) estimated that the global MSW generation is approximately 1.3 billion tons per year or an average of 1.2 kg/person daily. According to Fodor and Klemeš (2012), MSW commonly known as refuse or garbage, is discarded from residential, commercial, and institutional areas. Currently, the rate of MSW generation in many developing nations tends to burden the natural environment, as well as the authorities designated to manage it. Abumere et al. (1983) looked at the magnitude of solid waste generated annually in Nigeria and blamed the net effect on the oil boom recorded since 1970. He also stated that there must be a link between solid wastes generation and the rapid population growth in Nigerian cities.

On the other hand, Nigeria has struggled for years to meet its populace electrical power demand due to lack of its contingency plan in the power sector, limited technologies and most especially its inability to diversify into multiple sources of electrical power generation. Again, the abundant renewable energy resources in Nigeria have not been fully exploited. Therefore, long-term investments in renewable energy like biomass, solar and wind have the potentials to contribute significantly to electricity generation (Onochie et al, 2015a). However, Pytlar in (2009) reported that the energy potential in MSW is in materials that are of biogenic and anthropogenic origin. The researcher further described that biogenic materials include paper, food, and yard wastes while anthropogenic materials like plastics, can be used for energy production. Although, the availability of renewable energy resources such as hydro, tidal, solar, and wind varies with conditions such as the season of the year, time of the day, and location. Unlike the combustible components of the MSW which is always available all time all year provided there are inhabitants and anthropogenic activities present. Also, many households are facing low and inadequate supply of electricity, often rely on non-commercial traditional energy sources such as biomass (Urban et al. 2007).

Electrical power supply has been a major driver of development globally and it has contributed to the socioeconomic growth, industrial and technological prosperity of many advanced nations. Nigeria is currently suffering a tremendous drawback in the progressive industrialization economic growth because of its underdeveloped energy infrastructure (Olaniyan et al. 2018). According to the IEA (2017), annual per capita electricity consumption in Nigeria was 140 kWh in 2015, estimated to be as low as 12 kWh per capita monthly. In Nigeria, the mass combustion of MSW has been the usual and quickest practice of reducing the volume of waste at dump sites to free up space for incoming MSW. Although, Pires et al. (2011) reported that in developed countries such as European Union member states, Canada and USA, well-functioning approaches and effective policy measures (such as zero waste strategies and Waste-to-energy) have been designed and implemented to address solid waste management.

Waste management is an important objective of planning to ensure that the future generations inherit an environment that is as pollution free as possible given the present scientific, economic, social and political constraints (USEPA, 2005). The significance of waste management has been a global issue. However, in Johannesburg 2002, the World Summit on Sustainable development focused on waste minimization, recycle, and reuse followed by the safe disposal of waste to minimize pollution (UNWWSD, 2002). Although, the Nigerian government have been confronted with series of environmental pollution issues in the past. Hence, the government established the Federal Environmental Protection Act (FEPA) Act of 1988 and was later adopted into the 1999 constitution of the federal republic of Nigeria (Nwufo, 2010). The need for an environmental policy in the country was imperative, thus it was adopted in the Constitution of the Federal Republic of Nigeria, (1999) that “ in accordance with section 20 of the constitution, the state is empowered to protect and improve the environment and safeguard the water, air, land, forest and wildlife of Nigeria”. Among all other environmental laws in Nigeria, we have Waste Management Regulations; National Environmental Protection Regulation; and the Environmental Impact Assessment (EIA) Act (Aderoju et al, 2015). Nonetheless, the problem of MSW management persist.

The concept of integrated waste management (IWM) is targeted to control the waste generated from processes to meet the needs of the society at minimal environmental impact, and at an efficient resource usage by activating the potential of waste prevention, re-use, and recycling (Al-Salem et al, 2009). Recent estimates have shown that the waste sector contributes about one-fifth of global anthropogenic methane emissions (IEA 2005) and methane is a greenhouse gas that is 23 times more harmful than the same volume of CO_2 on climate change (IPCC, 2007). The IPCC in 2000, reported that waste sector emissions have grown steadily globally and are expected to increase in the forthcoming decades especially in developing countries like Nigeria because of the increase in population and GDP (gross domestic product) and as a result, the Clean Development Mechanism (CDM) established by Kyoto Protocol in 1997, recognized waste and its disposal as one of the sectors identified for greenhouse gas reduction. Again, the IEA, (2014), reported that the energy demand in Sub-Saharan Africa grew by around 45% from 2000 to 2012, but accounts for only 4% of global demand despite being home to 13% of the global population. Consequently, the increasing clamour for energy and satisfying it with a combination of conventional and renewable resources has been a huge challenge (Jain et al, 2014).

Presently, the sporadic power supply in Nigeria has severely impeded the socioeconomic growth of the nation (Aderoju et al, 2017). In addition, the Nigerian demand for electricity keeps increasing because of the country's energy supply infrastructure failed to expand as rapidly as population growth due to poor public investment over several years (Iwayemi, 2008). Over the years, the National Electric Power Authority (NEPA) had enjoyed the monopoly of generation, transmission, and distribution of electricity to end consumers (Ohajianya et al, 2014). However, the power reform process, NEPA was renamed as Power Holding Company of Nigeria (PHCN) in 2005 (Onochie et al, 2015b), having failed to meet the required demand and expectation of the people over the years. This has led to the establishment of a statutory regulatory commission namely; Nigerian Electricity Regulatory Commission (NERC) entrusted with the mandate to monitor all power generation, transmission, and distribution related activities in the nation's power sector. Nigeria as a nation basically generates its electricity from gas-fired power plants and hydro power plants. However, factors such as seasonal variation, inadequate generation, and distribution infrastructure, obsolete infrastructures, lack of recent technologies among others have hindered Nigeria's electricity supply. According to a study by (Onochie et al, 2015a), it was reported that about 20 out of 23 major power stations in Nigeria, putting electricity into the National Grid are fired by natural gas. Thus, the supply of electricity in Nigeria is highly dependent on the delivery of natural gas to these stations by the oil and gas companies.

Over the years, pipeline vandalism in Nigeria has contributed to pipeline and plant shutdown, environmental pollution, fire outbreaks, scarcity, and the shortage of petroleum products, and a decrease in electricity supply (Udofia and Joel, 2012). Also, pipelines are frequently vandalized to the extent that between June 2014 and June 2015, Nigeria National Petroleum Company (NNPC) recorded between 3400 to 4000 attacks on the various pipelines in the country (Kachikwu, 2015).

For this reason, there is a possibility that Nigeria can meet the electricity demand of its populace by diversifying into other existing energy sources that are not susceptible to seasonal variations and militancy attacks. However, studies have shown that the utilization of Waste to Energy (WTE) technology as an effective solution to the global MSW problems is a sustainable concept. Therefore, this study looks toward the WTE option as a sustainable solution to the electrical power supply issue in Nigeria. In addition, a technical report by ESMAP in 2007, rated biomass as one of the cheapest available renewable energy resources for power generation. Again, when embarking on a WTE study, it is important to tailor this concept towards the waste management hierarchy which includes: sensitization; waste characterization; recycling; recovery and sanitary landfilling especially in a country like Nigeria. Various studies have been conducted across the globe with researchers exploring the possibilities of utilizing the combustive part of MSW for energy. For instance, Babayemi and Dauda (2009) used structured questionnaire, interviews and personal observation to evaluate MSW generation, categories, and disposal options, and the level of awareness on waste management. However, the study focused on the capital city Abeokuta, Ogun state, Nigeria. From the results, it was deduced that 201 respondents to the administered questionnaires in Abeokuta, and 38.5% used the waste collection service; 64.2% used other waste disposal options, while 16.4% used both. Also, 68.7% were aware of waste collection service, and 58.7% were of waste management regulations respectively. However, 28.4% separated their solid waste at source.

Also, AbdAlquader and Hamad (2012) adapted the (ASTM D 5231-92) to determine the composition of the MSW in Gaza Strip, Palestine to support the integration of MSW management. The study used two fields surveys conducted during 2010 and 2011 to come to conclusion on the average composition of the MSW in Gaza Strip.

Ojuri et al (2018) employed an Integrated Risk Based Approach (IRBA) and administered questionnaires to evaluate the rehabilitation potential and the risk level of Igbatoro dumpsite, Akure, Nigeria. The Risk Index (RI) was evaluated from the addition of the sensitivity index output with the attribute weightage of the twenty-seven (27) parameters studied. A total Risk Index of 571.58 was obtained for Igbatoro dumpsite indicating moderate hazard evaluation. Also, a systematic sampling method was used to distributed questionnaires to dwellers around the dumpsite also showed that 83.6% of those interviewed agreed that the present management of the dumpsite is poor while 81.8% supported rehabilitation of the dumpsite.

On the other hand, Oyinloye and Fasakin (2013) used Geographic Information Systems (GIS) to determine suitable location for disposal sites in Akure, Nigeria. The study employed criteria which includes natural physical characteristics, socioeconomic, ecological and land use factors. The study used the Landsat ETM^+ of 2002, and the SRTM of 2011 were used for the LULC, DEM and the mapping of suitable location for disposal sites with the aid of ArcMap and Global Mapper software. The results show that sites were located within areas at 750m away from surface water; 300m away from major and minor roads; slope considered was between 4% and 12%; soil present in suitable locations possess low permeability (clay rich environment) which Luvisols, Regosois among others. It was concluded by mapping 4 potential sites with a total area of 5890.7 hectares.

Nwambuonmo et al. (2012) used GIS to select suitable landfill sites in Lagos Nigeria. The study employed GIS as a tool with satellite images (CNES SPOT 5) and topographic maps; Word Bank standard of landfill siting criteria to evaluate the existing landfill sites in Lagos and further proposed the need for new dump sites and proposes the candidate landfill sites. The World Bank standard of landfill criteria considered environmental, economic and sociopolitical factors.

Ohajianya et al, in (2014), identifies four major factors responsible for the erratic power supply in Nigeria namely: government policy; inefficiency in the power generation; transmission, distribution and consumption; and the incompetent staff of the energy companies. However, they recommended the following; an adoption of energy conservative policies; immediate discounting of default / estimated billing system; an upgrade of the power distribution and transmission equipment; and the engagement of competent and qualified staff by the energy companies.

Antonopoulos et al. (2010) structured a model to evaluate the energy potential of MSW by considering the existing legislation and infrastructure on waste management plants and its residuals. The study further assessed the direct impact of recycling and the diversion of organic waste on the heating value of the MSW. The results show that the diversion of food waste from the mixed stream of MSW increases the Lower Heat Value (LHV) of the residual while the recycling of packaging materials has a negative impact on the LHV. Also, in (2009), Akkaya and Demir developed a model for estimating and predicting the energy content of MSW using input parameters of the MSW compositions. The study used the elemental component data of MSW (C, H, O, S, N & H_2O) in a method of multiple regression analysis. The result shows that the developed model equation indicates a high performance with the coefficient of multiple determination (R^2) between actual and estimated Higher Heat Value (HHV) was found as 0.98.

Montejo et al, (2011), analyzed and compared MSW and RDF when used as fuel. The analysis was done by obtaining MSW and Refuse Derived Fuel (RDF) compositions from 36 samples of about 250 kg. Thereafter, it was taken into different mechanical-biological treatment plant (MBT plants). The results show that high percentage of combustible materials (plastic or cellulose) raised the energetic content to 10160 kJ/kg for MSW and 18281 kJ/kg for RDF. Hence, it was concluded that it is more profitable to use RDF as fuel compared to MSW.

Menikpura et al, (2007) also determined the energy potential of the MSW in Kandy Municipality, Sri Lanka. A bomb calorimeter was used to conduct the energy values of different MSW types that are combustible. The results showed that plastics and wood produced considerable amount of energy at minimum and maximum calorific values on dry basis at 14000 kJ/kg and 45000 kJ/kg respectively. It was concluded that the estimated energy potential produced by the MSW collected in Kandy at 69.3 GWh/year is twice the annual electricity consumption within limits at 33 GWh/year.

Kumar et al, (2010) utilized the MSW in Eluru city, India through a laboratory analysis using bomb calorimeter to estimate the Gross Calorific Value (GCV) at 1080 kcal/kg, and Net Calorific Value (NCV) at 940 kcal/kg. The study estimated that about 3 MW of energy could be generated from 60 tons of the MSW from Eluru city, India.

Sivapalan et al, (2003) identifies that a substantive amount energy could be recovered from MSW in Malaysia if it were to be incinerated. The study used the proximate analysis, ultimate analysis, and a bomb calorimeter through the ASTM E711-87 to estimate the calorific values of the Malaysian MSW. The results show that the calorific values range between 1500-2600 kcal/kg, and there is a possibility to generate about 640 KW/day if 1500 tons of Malaysian MSW with an average calorific value of 2200 kcal/kg.

Presently, there is a huge gap in the policy implementation; awareness creation; provision of basic infrastructure and modern technologies. This gap has exacerbated the problem of solid waste management in many Nigerian Cities. Therefore, this study has utilized various concepts and idea from the reviewed papers on other literature to bundle conceptual frameworks and methodologies as well as strategies to attain from the MSW in Abuja to supplement the present energy crisis and to structure an integrated waste management system.

1.2. Problem Statement

Municipal Solid Waste (MSW) generation as well as limited electrical energy supply in Nigeria are the most impending socioeconomic damage that needs to be properly addressed by the Nigerian government. Presently, Nigeria has a crisis of electricity such that a minimal and intermittent supply is the option used by the power generation company, which has made living standards become an obstacle for the socio-economic growth of the nation. On the other hand, heaps of MSW in disposal sites and the exponential population growth in the Nigerian urban areas is simultaneous to the quantity of MSW generated, which is of great concern to the authorities. The decomposition of organic waste in dumpsites continuously emits greenhouse gases such as carbon dioxide and methane gas which contribute enormously to the depletion of the ozone layer and global warming at large. As a result of the recurrent energy crisis in Nigeria, the importation of diesel and gasoline generators now remain a very lucrative business and it has promoted sabotage in the power sector. Again, the level of noise and the emission of greenhouse gases have led to the pollution of the environment as a result of the usage of generator plants. Nigeria's high dependence on hydro (which is seasonal), and natural gas (which is prone to sabotage) on electric power generation without diversifying into other sustainable energy source has led to the electricity supply of a little above 4000 megawatts for a population of over 188 million. Despite the efforts made by the Nigerian government to unbundle the electricity generation and distribution assets of the Power Holding Company of Nigeria (PHCN) to private investors, the demand for electricity is still higher than the supply in many Nigerian cities. This reason has ignited the urgent need to explore other means of electric power generation. The figure 1 below shows the 3 scenarios this study is trying to address in Nigeria. The situation in the figure reads: no electricity; the use of generation plant as an option for electricity which emits greenhouse gases; and the heaps of MSW littered on the streets which is likely to emit greenhouse gases on decomposition, blockage the of drainage system and also impair the health of the populace.

(a) No electricity supply (b) Use of generator plants (c) Indiscriminate dumping of MSW

Figure 1.0. Current Status of electricity and waste management in Nigeria.

1.2.1. Aim and Objectives

The principal aim of this study is to investigate on Municipal Solid Waste (MSW) as a complementary and potential fuel resource for electric power generation and distribution in Abuja, Nigeria.

The specific objective of the study is to:

a) Develop a concept that educates and promote sensitization in waste management merits, and environmental ethics and discipline.

b) Develop a methodology for MSW management and monitoring by integrating geo-spatial capabilities and techniques with existing ground-based data and technology.

c) find the most suitable sites for a sanitary landfill facility for environmental sustainability with respect to the existing standard guidelines.

d) Investigate the present solid waste generation, characterization and current management practices in (AMAC and Bwari area council), Abuja Nigeria.

e) Evaluate the calorific potentials of MSW streams using the (physical, chemical, and proximate) analysis.

f) Establish possible similarities for the power generation potential of MSW in Abuja, Nigeria and Porto, Portugal through a comparative method.

1.2.2. Justification of the Study

This study explores the Waste to Energy (WTE) option as an alternative solution to the problem of the erratic electrical power generation and distribution in Nigeria. For instance, the use of MSW for electrical power generation has grown with wide-range acceptability throughout the world. More so, this stands to boost the electricity supply for optimum socio-economic growth in the country. Furthermore, it will be of great significance to reduce excess MSW to attain a sustainable environment for the population. WTE is an area of Integrated Waste Management System (IWMS) that has not been fully explored in Nigeria. Nonetheless, this will help in the convert loose carbons in dumpsites to electricity and serve as a mitigation strategy for climate change. Also, WTE provides benefits such as; MSW minimization; sanitation and detoxification, energy recovery, generation and distribution, maintaining a sustainable aesthetic environment, job creation, revenue generation, transition of a clean energy economy, and most importantly build a baseline data for greenhouse gas reduction in Nigeria. It is understood that electricity is a basic need for the development of any nation since it contributes immensely to the improvement of socio- economic growth and the quality of life of its citizens. This study is in pursuance of the first two objectives of the Renewable Energy Master Plan in Nigeria which simply states; to enhance national energy security, and to expand access to energy especially in the rural areas. Hence this will guarantee environmental sustainability and a better quality of life for both the present and future generations of Nigeria.

1.3. Structure of the Thesis

The study presented is a research work developed during the past 4 years, in the scope of doctoral thesis titled "The Optimization of Municipal Solid Waste as a Potential Energy source for Power Generation and Sustainable Development in Nigeria". In a way to address the research problems, specific objectives were defined for the research to design ideal methodologies to arrive at the best possible conclusions with the aid of conceptual models, field surveys, laboratory experiments, mathematical evaluation, and basic statistics.

The study presented here does not obey the regular pattern thesis structure. However, it is comprised of a set of scientific works in the form of articles developed as the research was carried out. Therefore, this thesis is structured into 6 discrete chapters, and the chapter one is the introduction chapter of the thesis. Chapter 2 of the thesis described the study area environment. Chapters 3 to 5 comprise of published articles that tackles individual objectives of the study and the articles is comprised of theoretical background of the study, concept, procedure, analysis of results and discussion and conclusions. The chapter 6 consist of a general conclusion of the study and recommendations.

Table 1. Distribution of chapters in the study

Chapter	Title
1	General Introduction (Background of the study, problem statement, aim & objectives, justification of the study, scope of study, and structure of the thesis).
2	Study area, and study area characteristics.
3, 4, and 5	Published articles that tackles individual objectives of the study and the articles is comprised of theoretical background of the study, concept, procedure, analysis of results and discussion and conclusions.
6	General conclusions and recommendation.

Chapter 1: *Introductory chapter*

In Chapter, the overall theoretical background of the study where existing studies was reviewed and documented. Also, the problem statement for the research was established, and the aim of the study, and the specific objectives of the study as a guide to achieve the main goal of the research in the area of Waste management and energy recovery from MSW. In addition, the justification of the research was clearly defined.

Chapter 2: *Study Area*

The chapter consist of the information on the study area of interest. The description of the study area includes geology and soil, relief, demography, and climate. Also, a map and a statistical description of the population data of the study area were displayed.

Chapter 3*: Conceptual framework for educating and promoting sensitization in waste management merits, and environmental ethics and discipline.*

This chapter dealt with the issue of awareness creation amongst the inhabitants through sensitization and community participation. The conceptual framework was designed to educate the people on environmental ethics and discipline, waste management practices and solid waste management and its benefits in the society. This chapter consists of an article version (Aderoju et al. 2015) which is comprised of an introduction part which gives an idea of the background of study; the state of art which gives a general overview of solid waste management in Nigeria; a methodology that shows the organogram of the conceptual framework; the discussion part gives detailed description of the methodology and its merits; lastly, the conclusion emphasis on the main deductions from the study and few suggestions were made.

Chapter 4*: Methodology for solid waste management and monitoring by integrating geo-spatial capabilities and techniques with existing ground-based data and technology; also the selection of the most suitable sites for a sanitary landfill facility for environmental sustainability with respect to the existing standard guidelines.*

In this chapter, the principal object was to promote the optimization of space-based technologies as a tool in MSW management and sanitation monitoring using a conceptualized model. A methodology was developed to monitor and manage MSW in the environment by integrating geospatial capabilities and techniques, Information Communication Technology (ICT) with existing ground-based data and technology. This chapter consists of an article version (Aderoju et al. 2018a) and it is comprised of an introduction part which gives an idea of the background of study; state of the art section describes the geospatial technologies and ICT applications utilized in the study; methodology and discussion section shows the organogram of the geospatial model with; and conclusion.

In addition, a GIS-based analysis was carried out to identify suitable sites for MSW disposal in Abuja Municipal Area Council (AMAC) and Bwari area council of Abuja which meets global specification and standards. The integration of Geospatial data: Landsat-7ETM+, Nigeria Sat-X, ASTER-GDEM, base map, soil and geology maps and Multi-Criteria Evaluation (MCE) were used to evaluate the relative importance of each criterion in the study. This chapter consists of an article version (Aderoju et al. 2018b), which has an introductory part which gives an explanation on the background of the study; the methodology used; results obtained; discussion of results; and the conclusion.

Chapter 5: *Evaluate the calorific potentials of MSW streams using the empirical models (physical, chemical, and proximate) analysis and; Establish possible relationship for the power generation potential of MSW in Abuja, Nigeria and Porto, Portugal through a comparative method.*

In this Chapter, an article by (Aderoju et al, 2017) justified and described the merits of utilizing MSW as a resource for electrical power generation when compared to other renewable energy source in Nigeria. Furthermore, an investigation on the MSW in Abuja, Nigeria as a supplementary resource for power generation was carried out. The focus was on Waste to Energy by incineration as an instant solution for both MSW reduction as well as power generation. The study employs proximate and ultimate analysis to evaluate the Lower calorific values (LHV) for Porto & Abuja to determine the Power Generation Potential. The article version (Aderoju and Dias, 2018), has an introductory part that explains the background of the study; state of art; the methodology; discussion on possible results; and the conclusion. Also, in this chapter, the study estimates and compares the cities' power generation potential from the MSW in Abuja and Porto. The article version (Aderoju et al. 2019), comprises of an introductory part that explains the background of the study; the methodology; results and analysis of the laboratory experiments and field investigation; discussion of results; and the conclusion.

Chapter 6: *Conclusions & Recommendation*

This chapter includes conclusions which on the one hand present the summary of findings in the different stages of the study and recommendation on the other hand which suggest some measures with a view likely to improve the results, as well as to support future studies.

1.4 List of Publications in the Thesis

Book Chapter

1) Aderoju O.M, Dias A.G and Guimaraes R (2015): Building Capacity an Integrated Perception and Attitude towards Municipal Solid Waste Management in Nigeria. WASTES: *Solutions, Treatments and Opportunities*, Published by Taylors and Francis Group, London, pp 7-12, ISBN 978-1-138-02882-1.

2) Aderoju O.M and Dias A.G (2018): Waste to energy as a complementary energy source in Abuja, Nigeria. WASTES: *Solutions, Treatments and Opportunities*, Published by Taylors and Francis Group, London, pp 63-68, ISBN 978-1-138-19669-8.

Journal Paper

3) O.M, Aderoju, G.A Dias & G.J, Alberto (2018): A Spaced-based Concept in Municipal Solid Waste Management and Monitoring in Developing Countries. *International Journal of Environmental Impacts*., Vol. 1, number 4, pp 482-490. doi: 10.2495/EL-VI-N4-482-490.

4) O.M, Aderoju, G.A Dias & G.J, Alberto (2018): A GIS based analysis for sanitary landfill sites in Abuja, Nigeria. *Environment, Development and Sustainability*. (15) 5, p 1-24. Doi:10.1007/s10668-018-0206-z.

5) Aderoju O.M, Oke A.B and Dias G.A (2019): A Comparative Analysis of City-Based MSW for Power Generation*. Environment, Development and Sustainability*, Springer Nature (Under review).

Conference Proceedings

6) Olaide M. Aderoju, Guerner A. Dias and Zhour Echakraoui (2017): Assessment of Renewable Energy Sources & Municipal Solid Waste for Sustainable Power Generation in Nigeria. IOP Conf. Series: Earth and Environmental Science 95 (2017) 042043 doi: 10.1088/1755-1315/95/4/042043.

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6) Aderoju O.M, Dias G.A, and Goncalves A.J (2018b): A GIS based analysis for sanitary landfill sites in Abuja, Nigeria. Environment, Development and Sustainability. (15) 5, Pp 1-24. Doi:10.1007/s10668-018-0206-z.

7) Aderoju O.M, Dias A.G and Guimaraes R (2015): Building Capacity an Integrated Perception and Attitude towards Municipal Solid Waste Management in Nigeria. WASTES: Solutions.

8) Treatments and Opportunities, Published by Taylors and Francis Group, London, pp 7-12, ISBN 978-1-138-02882-1.

9) Aderoju O.M, Oke A.B and Dias G.A (2019): A Comparative Analysis of City-Based MSW for Power Generation. Environment, Development and Sustainability, Springer Nature (Under review for publication).

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2. Study Area

2.1. Research Study Area

Abuja is the capital city of Nigeria which came into existence by virtue of the Federal Capital Territory Act, of 1976. It is in the center of Nigeria in the Federal Capital Territory (FCT) within latitude 7° 25' N and 9° 20° North of the equator and longitude 5° 45'E and 7° 39'E of the meridian (Olajuyigbe et al. 2014). The FCT has a land area of 7,753.85 km^2. The FCT is bounded on the north by Kaduna State, on the west by Niger State, on the east and south-east by Plateau State and Nasarawa while on the south-west by Kogi State. Abuja is a planned city and was built mainly in the 1980s. It officially became Nigeria's capital on 12 December 1991, replacing Lagos, the previous capital. It is a multi-cultural with all kinds of people from various part of the country. Abuja has six Area Councils which are: Abaji, Kuje, Kwali, Gwagwalada, Bwari and Abuja Municipal. Abuja is known for being the best purpose-built city in Africa as well as being one of the wealthiest and most expensive (Olajuyigbe et al. 2014).

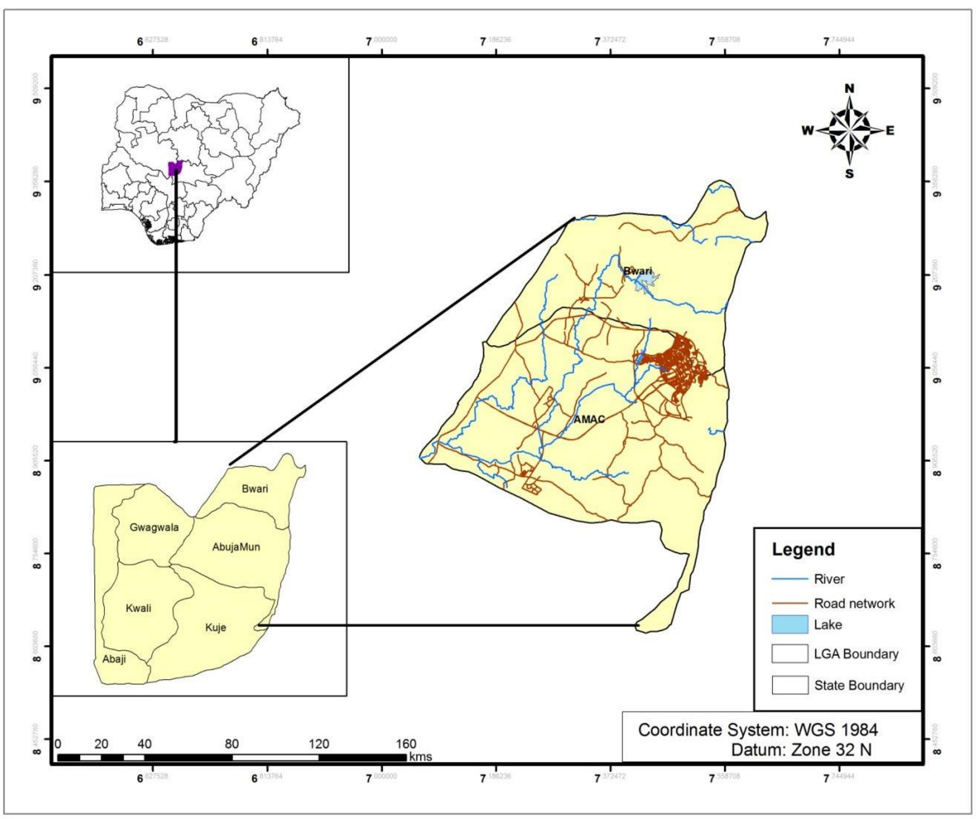

Fig. 1 Study Area Map.

2.1.1. Climate

The FCT experiences three weather conditions annually, and it includes warm, humid rainy season and a blistering dry season. In Mahmoud et al. (2016), it was reported that there is a brief interlude of harmattan occasioned by the northeast trade wind, with the main features being dust haze, intensified coldness and dryness. This begins in November until January/February. The topography, high altitudes and undulating terrain of the FCT act as a moderating influence on the weather of the territory (Mahmoud et al. 2016). Rainfall in the FCT reflects the territory's location on the windward side of the Jos Plateau and as a zone of rising air masses. (Balogun, 2005) reported that Abuja experiences an average daily minimum and maximum temperature of 20.5ºC and 30.8ºC respectively. He further stated that its minimum in August and September and the highest in January - March. Also, it has a mean rainfall and humidity of about 119.2 mm and 58.4% respectively with the highest in August and lowest between November and March respectively.

2.1.2. Vegetation

The FCT within where Abuja falls within the guinea savannah vegetation zone of Nigeria (Anondonkaa, 2012). The vegetation is southern Guinea Savannah biome characterized by deciduous trees scattered among grasses. Patches of rain forest, constituting about 7.4% of the total mass of vegetation, however, this occurs in the Gwagwa plains, especially in the rugged terrain to the south eastern parts of the territory, where a landscape of gullies and rough terrain is found (Balogun, 2001). However, some of the areas are forested because they have not suffered much devegetation while some of the forests fringe the streams which are relatively wet all over the year.

2.1.3. Demography

The FCT has a population of about 2,238,800 persons (NPC, 2011). However, the study area (AMAC, and Bwari area council) in Abuja has a population of 1,600,880 persons (see table 1) which was reported to be the two most populated area council of the Abuja (NPC, 2011). The FCT have undergone a huge population growth with some areas around Abuja growing at an exponential rate year. Abuja was planned as a capital where all Nigeria's ethnic groups, and religions would come together in harmony. It has avoided the violence prevalent in other parts of Nigeria, which has more than 250 ethnic groups. The population in the FCT include the Afo, Fulani, Gwari, Hausa, Koro, Ganagana, Gwandara, and Bassa ethnic groups.

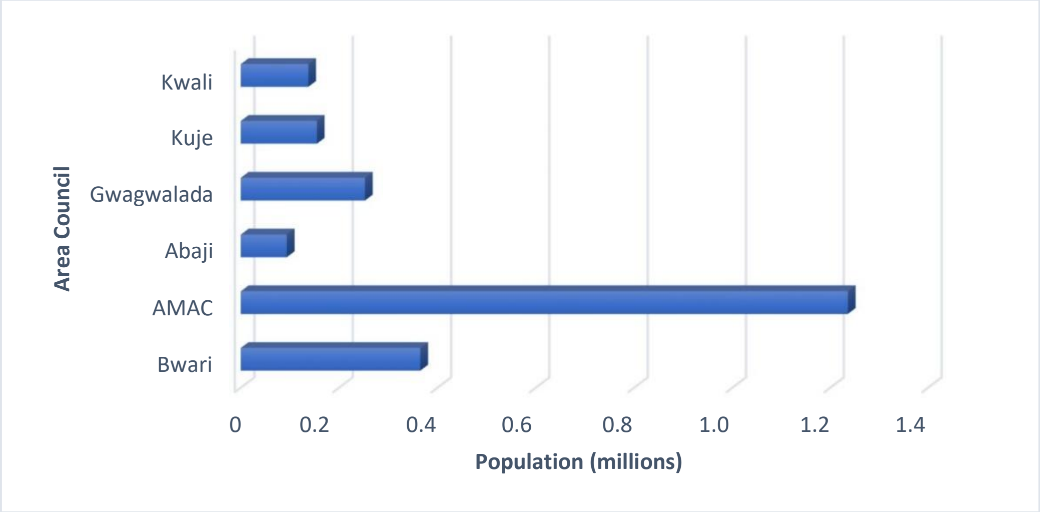

Figure 2. FCT population data. *Source* (NPC,2011)

2.1.4 Geology and Soils

Abuja's geography is defined by Aso Rock, a 400-metre batholiths left by weathering and erosion (Abam,2012). The FCT has two broad geological regions with each one having similar structural and lithological characteristics. These regions comprise the Pre-Cambrian Basement Complex and sedimentary rocks, which both have very strong influence on the morphological characteristics of the local soil (Ola, 2001). A schist belt outcrops along the eastern margin of the area. Also, the belt broadens southward and attains a maximum development to the southeastern sector of the area where topography is rugged and the relief is sheared (Kogbe,1978). Also, a few local soils that have been identified within the FCT are the alluvial soils, Luvisols and Entisols (Enahoro and Ogbonnaya, 2015).

2.1.5 Relief

Topographically, the area is typified by gentle undulating terrain interlaced with riverine depressions and generally; the local relief from hilltops to valley bottom varies around 50 m (IPA, 1979). The FCT has its landscape profiled by rolling hills isolated highlands and gaps with low dissected plains (NTDC, 1997). In 2006, Ojigi reported that the South West Area has the lowest elevation where the flood plain of Gurara Rivers having the lowest elevation of about 61 m above the mean sea level. Furthermore, he stated that the land rises irregularly from Gurara River eastwards to elevation of about 915 m above mean sea level. The study area (FCC) falls within the Gwagwa plains with terrain elevation ranging between 305 m in the west to 610 m in the east, (Ojigi, 2005).

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3.

Education and Outreach concept on waste management merits, and environmental ethics.

3.1 Introduction

The irregular and indiscriminate dumping of Municipal Solid Waste (MSW) in our environment especially during the quiet period of the day is of gross violation of existing policies. This action has however hindered the aesthetic nature of our environs and poses a health risk to the inhabitants of our communities. Several studies have shown that developing countries have a long way to breach the gap of education and outreach to the population. Hence, there is a need for thorough sensitization programs in the cities and rural communities in developing countries.

The lack of proper education and outreach to the inhabitants of the Nigerian cities on effective and efficient practices of MSW management through its safe disposal is building up to explode into a future environmental catastrophe. However, the merits of resource recovery from disposed MSW stream as well as the stakeholders' participation in carrying out basic responsibilities is imperative. This simply implies that the responsibility of the authorities and other stakeholders providing basic infrastructures and timely right service for the people should be defined and implemented in order to forge ahead to attain an efficient waste management program.

The article (Aderoju et al. 2015) titled "Building an integrated perception and attitude towards municipal solid waste management in Nigeria" designed a conceptual framework to address the limited awareness and education on environmental ethics and waste management benefits. This approach cut across all stakeholders thereby utilizing specific channels of communication with an effective procedure to get the message across to the inhabitants of the society.

Wastes: Solutions, Treatments and Opportunities – Vilarinho, Castro & Russo (eds)
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3.2 Building an integrated perception and attitude towards municipal solid waste management in Nigeria

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ABSTRACT: Municipal Solid Waste Management (MSWM) as an integral part of the urban environment that require proper planning to ensure the safety of human and its environment. Nigeria became an increasingly urbanized society because of the oil boom in the 1970s. Rapid population growth simultaneously increases the quantity of waste generation in any society. Again, environmental indiscipline, poor management practices by the authorities, non-implementation and enforcement of the environmental laws attribute to indiscriminate dumpsites in our cities. Hence this study aimed at the behavior of Nigerians towards municipal solid waste disposal using an integrated approach. The methodology adopted was a conceptual framework which has four stages (Initiators, Channel, procedure, and recipient). In conclusion, incorporating the conceptual framework it into the formal solid waste management structure in Nigeria will encourage self-discipline, educate the people, promote pollution free and sustainable environment.

1 INTRODUCTION

Managing municipal solid wastes (MSW) is obviously becoming a major challenge in major cities of developing nations due to rapid urbanization and increasing population growth. Saheed et al. (2008) reported that the generation of solid waste is directly proportional to population, industrialization, urbanization and the changing lifestyle, food, habits and living standards of the people. According to recent estimates, the waste sector contributes about one-fifth of global anthropogenic methane emissions (IEA 2005). Various activities of the society lead to the generation of waste materials that include both organic and inorganic wastes (Naveen et al., 2014). Municipal Solid Waste (MSW) are commonly known as trash or garbage that consist of everyday item like food item, metal scrap, polythene, and paper among others (Cunningham and Saigo,1997). Waste management is an important objective of planning to ensure that the future generations inherit an environment that is as pollution free as possible given the present scientific, economic, social and political constraints (United States Environmental Protection Agency, 2005). Municipal Solid Waste (MSW) management involves various steps, namely collection, transportation, processing and disposal and perhaps open land disposal is the most common method adopted in most developing nation like Nigeria. Babayemi and Dauda (2009) described the solid waste management in Nigeria as being challenged with ineffective collection technique, inadequate coverage of the collection routine and unlawful dumping of solid waste. In Portugal, we observed that the people have been able to consent that the reduction of environmental pollution contributes immensely to the environmental sustainability of their cities. This is probably the same standard of perception of most people all over Europe due to the high level of awareness on solid waste management.

In Nigeria, municipal waste disposal management has received a lot of attention with little done. Pronouncements of waste management programmes were made in the past but lacks political will and implementation. With little awareness on integrated waste management by its people, the pattern of disposal of refuse and poor management practice by the authorities has led to an increasing number of indiscriminate dumpsites the urban cities. Hence this study is aimed at the behavior of

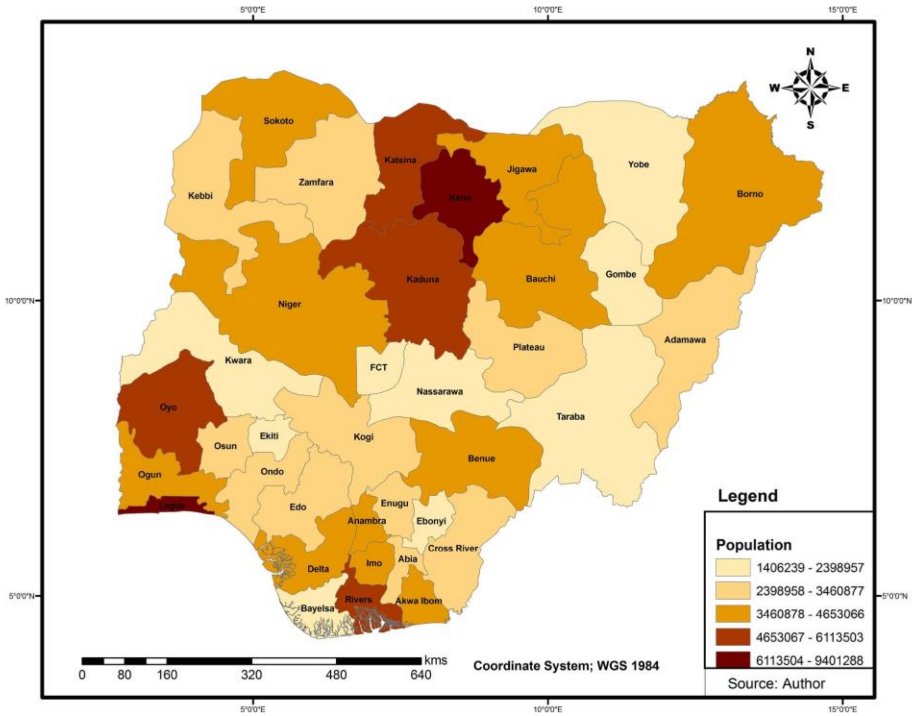

Figure 1. Nigeria population distribution map.

Nigerian towards municipal solid waste disposal and management using an integrated approach. The objective is to educate the people on environmental ethics and discipline and to promote the involvement of institutions and citizen participation in the waste management sensitization programmes.

2 AN OVERVIEW OF SOLID WASTE MANAGEMENT IN NIGERIA

Nigeria is a country located in the western part of the African continent, covering a landmass of approximately 924,000 km^2. It lies between the latitudes 5˚N and 15˚N and longitudes 5˚E and 15˚E. Nigeria as a nation has 36 states and the Federal Capital Territory (FCT) which are collectively constituted of 774 Local Government Areas; Solid Waste Management has been identified as one of the major environmental challenges being faced in the country (Adeyinka et al., 2005). Nigeria has a population of about 170 million, an estimated growth rate of 2.6% and is placed 7th only behind China, India, the United States, Indonesia, Brazil and Pakistan on a global population ranking (CIA, 2012, Agbesola, 2013). It is blessed with so many natural resources like crude oil, natural gas, limestone, gold and as many among others. Nigeria became an increasingly urbanized and urban-oriented society because of the oil boom in the 1970s. During the 1970s, Nigeria had possibly the fastest urbanization growth rate in the world (Ochuo 1986; ICMPD 2010). The Figure 1 shows the Nigeria population distribution map of the 2006 census leaving Lagos and Kano to be densely populated among other states.

The impact of urban growth has led to an increasing volume and variety of solid waste, resulting from increased flow of goods and services and changed lifestyle and consumption pattern. (Solomon 2009, Nabegu 2011) in their research quoted the Federal Ministry of Environment and Housing that the municipal solid waste generation for average Nigerian communities with

Table 1. Waste generation in some urban cities in Nigeria.

City	Population	Agency	Tonnage/ month	Density (kg/m^3)	kg/ capita/day
Lagos	8,029,200	Lagos state waste management authority	255,556	294	0.63
Kano	3,348,700	Kano state environmental protection agency	156,676	290	0.56
Ibadan	307,840	Oyo state environmental protection commission	135,391	330	0.51
Kaduna	1,458,900	Kaduna state environmental protection agency	114,443	320	0.58
Port Harcourt	1,053,900	Rivers state environmental protection agency	117,825	300	0.60
Makurdi	249,000	Urban development board	24,242	340	0.48
Onitsha	509,500	Anambra state environmental protection agency	84,137	310	0.53
Nsukka	100,700	Enugu state environmental protection agency	12,000	370	0.44
Abuja	159,000	Abuja environmental protection board	14,785	280	0.66

Source: All sites engineering Ltd. (Ogwueleka, 2009).

household and commercial centres is 0.49 kg/capita/day. Table 1 shows the waste generation in some major Nigerian cities.

As shown in Table 1, waste density in Nigeria ranges from 280–370 kg/m^3 with waste generation rate of 25 million tons annually and at a daily rate of 0.44–0.66 kg/capital/day (Ogwueleka, 2009). Nabegu in 2011 reported that in most cities across Nigeria, solid waste is disposed by transporting and discharging in open dumps location almost close to residential areas, which are environmentally unsafe. The collection from dump sites is the function of state and local government agencies. Informal solid waste collection operations exist in parallel with official agencies in most major cities in Nigeria. There are inadequate service coverage as only limited areas of the cities are covered (Ogwueleka 2003; Nabegu 2009). Ogbonna et al. (2002) also observed that little or no attention is given to some traditional suburban settlements for provision of waste collection and disposal services. The sources of solid waste generation in Nigeria among others are basically from commercial, industrial, household, agricultural and institution of any kind. In 2005, Adewunmi et al. deduced that in Ibadan the capital of Oyo, the total solid waste generated was 66.1% for domestic, 20.3% commercial and 11.4% industrial. Several states in the country are coming up with various means of waste collection procedures which is initiated by both public and private sectors, although the effectiveness of this is largely a function of location; and where the collection is done by private sectors, it is a function of income of the owner of the waste to be able to pay the amount charged (Babayemi and Dauda, 2009). With regards environmental legislation, the unfortunate incident of dumping of toxic waste from Italy at Koko port in the then Bendel state in the 1988 prompted to establish Federal Environmental Protection Agency (FEPA) Act of 1988. FEPA vested with the statutory responsibility for overall protection of the environment. It is in the light of this reality that very interesting strides were taken by Nigeria government decided to establish the Federal Environmental Protection Agency and its inspectorate and enforcement department in 1991 (Nwufo, 2010). In 1999, Nigeria embraced democracy after a long reign of military rule. The need for an environmental policy in the country was adopted in the 1999 constitution of the Federal Republic of Nigeria which states" In accordance with section 20 of the constitution, the state is empow- ered to protect and improve the environment and safeguard the water, air, land, forest and wildlife of Nigeria. Among all other environmental laws are Waste Management Regulations, National Environmental Protection Regulation, and the Environmental Impact Assessment (EIA) Act.

3 CONCEPTUAL FRAMEWORK FOR SUSTAINABLE MUNICIPAL SOLID WASTE MANAGEMENT

The conceptual framework (see Figure 2) is to remodel the attitude of the Nigerian people towards a successful and sustainable waste management program. In every waste management program,

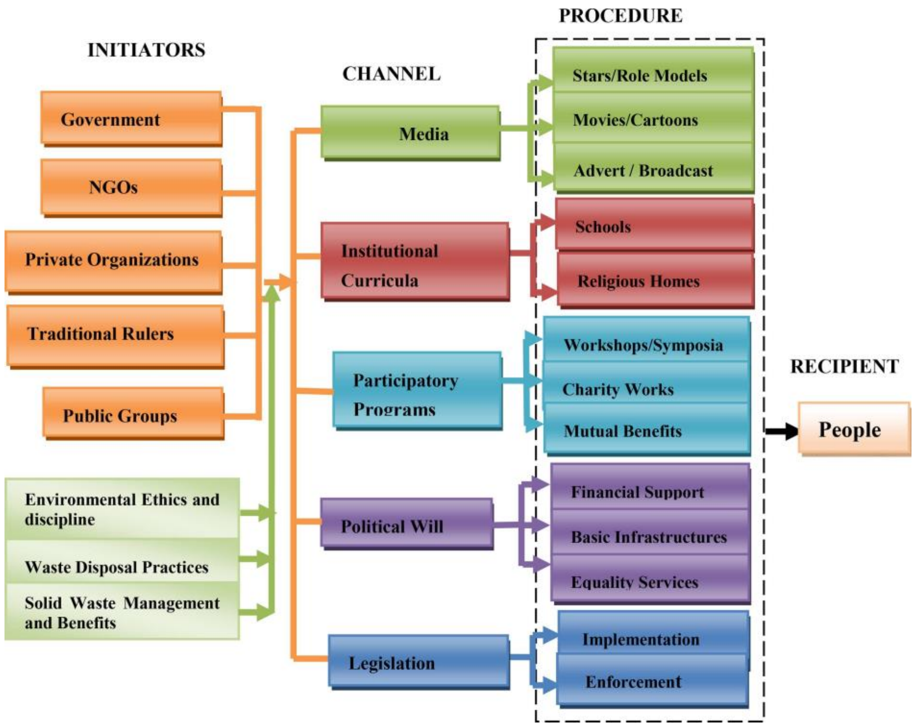

Figure 2. Concept of waste management sensitization program.

the evacuation phase is very significant. It is imperative to educate the people on the hierarchy of Integrated Waste management program, the health risk and possible benefits that is attainable. This simply the 3Rs refer to the reduction in the amount of waste being generated, the reuse of items prior to their being commissioned as waste, and the recycling of items once they become waste. In the light of this, the framework focuses on educating the people on environmental ethics and discipline, waste management practices and solid waste management and its benefits.

4 DISCUSSION

This concept comprises of 4 major stages (initiators, channel, procedure and the recipient) with the initiators as the principal actors educating the people on environmental ethics and discipline, waste management practices and solid waste management and its benefits. The Figure 2 describes the waste management sensitization program as follows; the initiators comprises of the government, NGOs, Private Organizations, traditional rulers as well as the public groups. The initiators carry out their responsibilities through a set of channels. This set of channel includes the media, institutional curricula, participatory programs, political will and legislation.

The media is one of the best ways of reaching out to the people/public to pass on information because people spend much time using one form of the media service harnessing information and for pleasure. This is done using sport/movie stars and role models to educate people on environmental ethics and discipline on solid waste management through movies, television series, comedy shows, cartoons, animation, video games, social media, music and radio adverts and broadcast, billboards and many more.

Institutional curricula are another smart way of educating the kids, youths and adults in schools (elementary, high and tertiary), orphanage homes, and religion homes on environmental ethics and discipline regarding solid waste and more. This is simply because kids/youths believe strongly in their teachers and tend to reflect whatever they are taught in their daily lives. Again, in religious homes, the fear and believe in the words of God has made people practice whatever that is taught for the benefit of man.

Participatory program involves incorporating the people of the society into the sensitization program from the start of the program/project which automatically craves their indulgence on the importance of solid waste management to their environment. In doing this, organizing workshop programs, symposia and talk show, charity work among the recipient (people) goes a long way educating them. Another aspect of this participatory program is the mutual benefit logic which involves companies recovering recyclables materials from homes through institutional arrangement. Schools instruct students to bring certain quantity of plastic bottles in from their homes which attract remuneration on the part of the schools and students.

Political will simply means the government should be committed providing support to the campaign on solid waste management program by providing financial support, employ dedicated youths to educate the people, provide basis infrastructures and assure services provided would be of equal interest irrespective of the individual or set of elite.

Legislation is basically the implementation of the available environmental laws and enforcement with respect to waste disposal and management. People should be aware of such laws and if defaulted, it attracts heavy penalty

Recipient's (people's) mind will be enlightened and refined in terms of perception and attitude towards in environment and particularly solid waste because of constant and continuous education and understanding on environmental discipline and solid waste management in general. With the media disseminating environmental education to the people during official and leisure times, schools and religious homes teaching environmental discipline and norms, citizens are practically involved in environmental participatory programs and projects, and the government fulfilling its goals towards pursuing an environmental friendly society for its people, and finally proper implementation and enforcement of environmental legislation, the people (recipient) will adhere and adjust to the new environmental consciousness of the society.

Since the youths of today are the ambassadors of the future, it is expected that environmental discipline, perception and attitude of the Nigerian people and the world at large on municipal solid waste disposal and management will be passed on to the generations to come.

5 CONCLUSION

Nigeria has a long way to go in environmental education and awareness for the citizens to put off the habit of indiscriminate waste disposal. This problem is also a function of non- implementation and lack of enforcement of the existing environmental laws. This study gives an insight that by incorporating this conceptual framework it into the formal solid waste management structure in Nigeria, a safer, healthier working condition is assured. Public education on solid waste disposal and segregation is of great importance. Municipal solid waste disposal and management is not solely the responsibility of the government but also requires self-discipline, change in perception and attitude of the people in order build a sustainable environment. The researcher recommends that government should give priority to solid waste management to prevent environmental disaster in our society. Solid waste management sensitization and environmental education programs should be extended to the rural communities and should be continuous and not to be abolished by any government so that a good solid waste management culture is built and passed on to the coming generation. Solid waste management policies and enforcement of sanitation laws in various arms of the government should be implemented, and the researcher urges all stakeholders to more until a utopian environment in Nigeria becomes a reality.

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4.

Methodology for solid waste management and monitoring by integrating geo-spatial capabilities, techniques with existing ground-based data and technology; also, the selection of suitable sites for a sanitary landfill facility.

4.1. Introduction

Technological advancement has helped in mitigating, monitoring, and management of MSW effectively in developed countries. Although, many developing countries still suffer from health risks, flood disasters, epidemic breakouts, among others, due to inadequate infrastructures and weak technological approaches to tackle the problems of excess MSW in the environs. The developed nations have evolved by incorporating technologies such as geospatial technologies (Geographic Information systems (GIS), remote sensing, Global Positioning System (GPS) among others) with Information Communication Technology (ICT) which includes Radio Frequency Identification (RFID) and General Packet Radio Services (GPRS)) into managing their MSW issues.

Furthermore, several reports show that GIS-based technology was considered and utilized to identify suitable sites for a sanitary landfill in most developed cities. In recent times, there has been a global campaign on sustainable MSW management in developing countries as the health risk on the populace, and the rate of environment pollution has raised a lot of concerns. Haphazard dumping of solid waste in the environment is a common practice in many developing nations. Hence, the need to employ these technologies to solve the menace MSW management is imperative.

Consequently, it is noteworthy that effective technologies such as geospatial technology and ICT using appropriate methodologies can be deployed to tackle the menace of MSW management in the society of developing nations such as Nigeria. The articles (Aderoju et al. 2018a; Aderoju et al. 2018b) in this chapter developed a generic methodology for solid waste management and monitoring in the environment; and identifying the most suitable sites for a sanitary landfill facility using the most appropriate criteria for the study area.

4.2 A SPACED-BASED CONCEPT IN MUNICIPAL SOLID WASTE MANAGEMENT AND MONITORING IN DEVELOPING COUNTRIES

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ABSTRACT

Lack of proper framework, ineffective policies, limited basic facilities and weak technological approach in the solid waste management sector have raised environmental concerns in major cities of most developing countries. Also, uncoordinated disposal pattern of municipal solid waste in the society contributes to the emission of greenhouse gases and other forms of pollution that is detrimental to human health and the environment at large. In bid to achieve an aesthetic and sustainable environment, the study aims to promote the optimization of space-based technologies as a tool in municipal solid waste (MSW) management and sanitation monitoring using a conceptualized model. The approach employed the use of geographic information systems (GIS) and remote sensing (RS), building a geodatabase in municipal solid waste management as baseline data for the nation, radiofrequency identification (RFID), GPS and GPRS/GSM and other ancillary data in solid waste management and monitoring. The incorporation of geospatial data with technology and integrated communication technologies in MSW management and monitoring for developing countries will enhance environmental sustainability and budget planning for contingency plan to assist decision-makers build a sustainable platform in the solid waste *sector*.

Keywords: environment, GIS, management, monitoring, MSW, RFID.

1 INTRODUCTION

The world will continue to generate municipal solid waste (MSW) in high quantities and varieties as a result of rapid urbanisation, industrial development and socio-economic impact which in turn has become an environmental issue that requires urgent attention by every nation. In 2009 [1], in its report stated that the estimated total amount of MSW generated globally is increasing by some 8% per year. A recent study by the World Bank [2] estimates that the global MSW generation is approximately 1.3 billion tonnes per year or an average of 1.2 kg/capita/day. Currently, as a result of industrialization and rapid population growth in many cities and towns in most developing countries, MSW are generated faster than they are collected, transported and disposed [3]. The significance of waste management has been a global issue such that in 2002, the World Summit on Sustainable Development focused on waste minimization, recycle and reuse followed by the safe disposal of waste to minimize pollution [4] in [5]. Inefficiency in MSW management in most developing nations is attributed to lack of appropriate technology, weak institutional framework, poor staff welfare, environmental indiscipline and non-ethical disposal methods, among others. Improperly sited open dumps have defaced several cities, thereby endangering public health by the spread of odour and diseases, and also the pollution of surface and ground water sources [6]. Presently, it is evident that pollution transforms the environment into an epidemiologic space [7]. The World Health Organization (WHO) had its concern about poor sanitation in member countries such that in a resolution by the Regional Committee for Africa during the Forty-Third session, stated in its document AFR/RC43/R2 of 7 September 1993, that it is expedient to affirm that proper sanitation and sound waste management are crucial in the

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promotion and protection of human health and of the environment, both of which are necessary for sustainable development [8]. In most African cities, issues of the proper management of solid waste still exist such that MSW are buried, burnt or disposed haphazardly. MSW, when left in the open dumps for a long time, constitutes serious health hazard, causes offensive odour, pollutes underground water sources and decreases environmental aesthetics, and quality [9] reported that MSW management planning is important to ensure that the future generation inherits a pollution-free environment given the present scientific, economic, social and political constraints. It is unfortunate that in most developing countries, statistical data on MSW and management records are inconsistent due to lack of funds, low-level coverage of MSW collection, lack of technical know-how, limited technology employed and infrastructural inadequacy. The use of geospatial technology has been an integral part of the developed nations all over the globe used in solving environmental-related issues. Geospatial technology can be described as a combination of equipment used in visualization, measurement and analysis of earth's features typically involving such systems as GPS, geographic information systems (GIS) and remote sensing [10]. It is popularly used in the environmental monitoring, military operations, national and internal security, socio-economic and urban management and health mapping, among others. GIS can simply be described as an informative system that collects, manages, analyses, manipulates and retrieves geographically referenced data. GIS was also used as a framework for mapping and displaying information about waste sites and processes [11]. On the other hand, remote sensing is the technology used in the acquisition of spatial information about an object or phenomenon through a device in order to identify, classify, map, monitor, plan, mitigate and manage the environment without being in contact either the object or the phenomenon under study. Space-based information is used in developed nations to assist public agencies and other stakeholders to prepare and mitigate the consequences of environmental sanitation issues. Therefore, it is imperative to explore geospatial techniques to solve socio-economic and environment needs such as solid waste management and environmental sanitation monitoring. In the light of this, the study aims to promote the optimization of geospatial technology as a supportive tool in MSW management and sanitation monitoring in developing countries using a conceptualized framework.

2 REMOTE SENSING SATELLITE AND APPLICATIONS

Remote sensing data from the Earth Observing Satellite Systems (EOSS) now constitute a major source of primary data for diverse studies and mapping, monitoring and management of natural resources and environment. Since the beginning of space science in the 1960s, satellite remote sensing has been recognized as a valuable tool for viewing, analysing, characterizing and making decisions about our environment [12]. Satellite remote sensing can be described as the use of satellite-borne sensors to observe, measure and record the electromagnetic radiation reflected or emitted by the earth and its environment for subsequent analysis and extraction of information [13]. It was from this point countries adopted the usage of satellite imageries for inventory, assessment, monitoring and management of resources from local to global scale. Remote sensing satellites are either active sensors (self-generating energy source) or passive sensors (dependent on the sun for energy). Satellites with active sensors operates during the day and night while those with passive sensors operates only during daytime. Images from remote sensing satellites are known as digital images which may be viewed as an array of numbers or matrix whose row and column indices identify a point in the array. The matrix element value is between 0 and 255, which corresponds to the brightness level at that point on the image [14]. The size of each pixel on the ground (called the spatial resolution of any given imaging system) differs from one imaging system to another. The ground coverage of a complete image scene and also the total number of pixels per image scene vary from one satellite system to another. The improvement in the spatial resolution of the remotely sensed imagery has provided a channel for geospatial data acquisition in the generation of essential geoinformation needed in many earth-based disciplines for various applications. Remote sensing satellite application areas include environmental management and monitoring; disaster management; military and security; infrastructure mapping; settlement classification; precision agriculture; border security and access control mechanism, regional planning and development.

3 GLOBAL POSITIONING SYSTEMS (GPS) AND GENERAL PACKET RADIO SERVICE (GPRS) TECHNOLOGY

Global Positioning System (GPS) can be described as a satellite-based navigation system placed in orbit to transmit signals to a device (GPS receiver) which allows land, sea and airborne users globally to determine their exact location and distance on the earth in real time and all season. GPS receiver can be used to determine an object's position in three dimensions. GPS receivers require an unobstructed view of the sky, so they are used only outdoors and they often do not perform well within forested areas or near tall buildings [15]. In recent times, GPS is extensively being used in motor vehicle to determine vehicles' position on an electronic map display, help drivers to keep track of their position, and also for providing emergency roadside assistance [16]. Modern systems automatically create a route and give turn-by-turn directions to designated locations [17]. Hence, GPS will be an effective tool in MSW management and monitoring by its use in tracking the position of waste collection trucks and bin location. GPRS is a packet-based data bearer service for wireless communication services that was developed from the existing GSM system which is related to the internet. Furthermore, GPRS applies a packet radio principle to transfer user data packets in an efficient way between GSM mobile stations and external packet data networks at the rate up to about 117 Kbits/s [18]. It provides an immediate and continuous connection set-up to the internet. GPRS network has a wide coverage and can truly achieve real-time sending and receiving [19].

4 RADIO FREQUENCY IDENTIFICATION TECHNOLOGY

Radio frequency identification (RFID) technology has already proven its use in various sectors such as agriculture and production; products supply chain; education; animal forms; sports; military and security; hospitality and tourism; health-care services; and airline. This technology can simply be described as an automatic identification method that uses wireless electromagnetic fields to transfer data for purpose of automatic recognition, thereby tracking tags attached to objects. Abiona in [20] also defined RFID technology as an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders. RFID reader generates magnetic fields through antennas for getting acknowledgement from tags [21]. The reader generates query (trigger) through electromagnetic high-frequency signals (this frequency could be up to 50 times/second) to establish communication for tags [22]. Hence, this technology enables readers to capture information on tags and transmit it to a central control system without any physical contact. A typical RFID system component is displayed in Fig. 1.

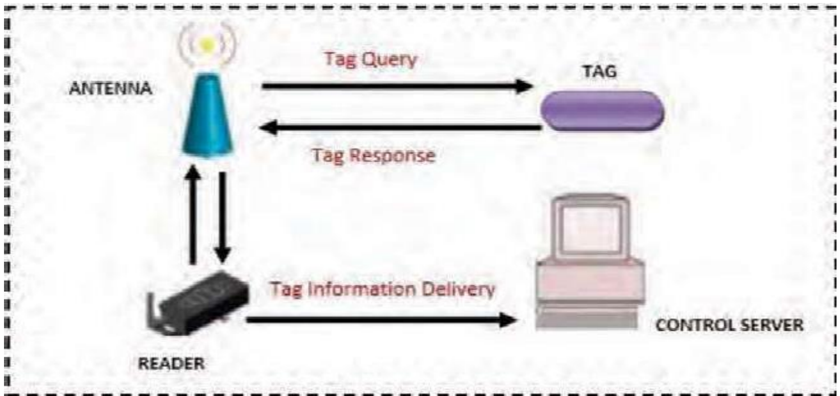

Figure 1: A typical RFID system component; Source: Author.

5 METHODOLOGY AND DISCUSSION

This proposed method is a conceptualized approach which includes a GIS and remote sensing component, and the integrated technology (GPS, RFID and GPRS) component. This system is a combination of the above-mentioned components to enhance an effective and efficient MSW management and monitoring in the society. The schematic in Fig. 2 describes

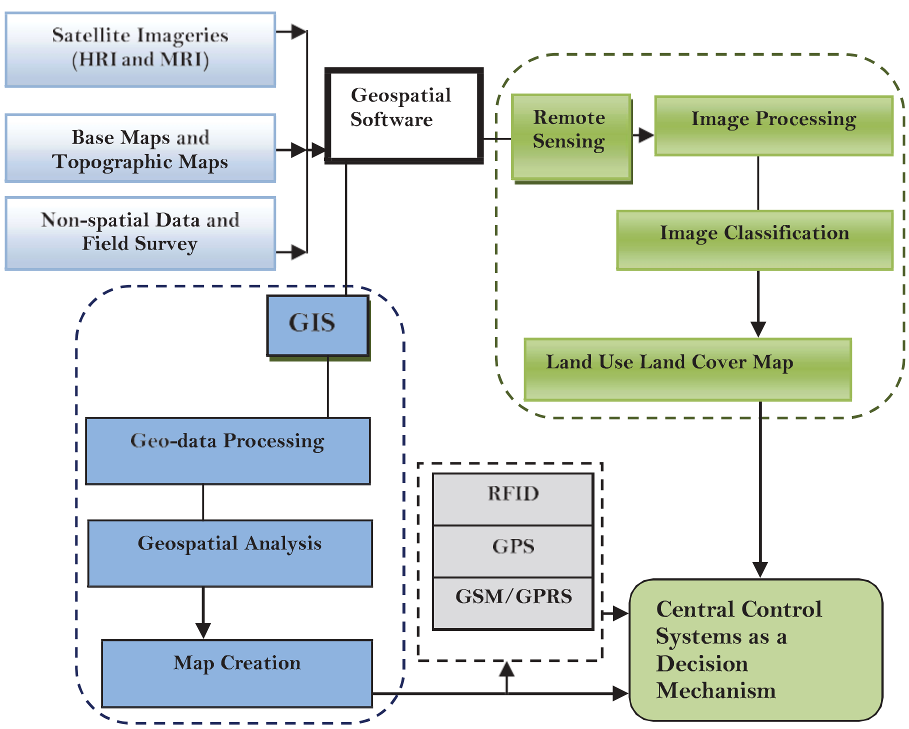

Figure 2: Geospatial model for MSW management and monitoring; Source: Adopted from [23].

the workflow of the conceptualized approach towards attaining a sustainable and effective MSW collection and monitoring in developing nations.

The conceptual model (see Fig. 2) is an approach designed for developing countries having known that it has capacity to pursue the task and achieving the goal of the study. This methodology requires spatial and non-spatial data, geospatial software, hardware and other ancillary information for the monitoring and management of MSW. The conceptual model is of two phases, namely the remote sensing and GIS phase, and the RFID phase.

5.1 Geospatial component

In the first phase, satellite imageries (high-resolution imageries (HRI) and medium resolution imageries (MRI)), base maps and topographic maps are the inputs into the central control system otherwise known as the system server. The presence of geospatial software (remote sensing and GIS) in the server provided gives room for various task to be executed such as image processing, georeferencing, geodatabase creation, geoinformation extraction, geospatial analysis, route network and proximity analysis can be done as a baseline data and information for the real task ahead. Validation exercise is imperative by conducting field investigation to confirm the reality of some feature as observed in the satellite images. This in combination tends to the generate various maps such as land use land cover maps, route maps, bin location maps, proximity maps and landfill suitability maps. Furthermore, spatial query can be demonstrated having created a geodatabase with information from spatial and non-spatial data sources. This will enable checks on operations, monitoring bins distributions and maintenance of the operations and sustainable management in general. Table 1 contains typical data required for a geodatabase in an MSW management and monitoring operation. The geodatabase uses the concept of database systems (DBS) in its operation. DBS are leveraged for managerial understanding of process relationship, inventory management and prediction [24] in [25]. Hence, this will improve the quality of decision-making in the planning, evaluation, forecasting scenario and alternatives in MSW management and monitoring. Tables 1 and 2 shows a typical database for proper monitoring and management in the MSW sector. The database consists of both spatial and non-spatial data component.

Table 1: Spatial database in MSW management.

Data	Type	Geometry
Road network	Vector	Line
River	Vector	Line
Contour map	Vector	Line
Waste bins location	vector	Point
Study area map	Vector	Polygon
Buildings	Vector	Polygon
Landfill	Vector	Polygon
Existing run routes	Vector	Line
Topographic map	Vector/Raster	
Base map	Vector/Raster	
Satellite imageries	Raster	

Table 2: Non-spatial database in MSW management.

Data	Type
Street addresses	Tabular
Road network attributes	Tabular
Waste bins attributes	Tabular
Land use data	Tabular
Population data	Tabular
Service provider's data	Tabular
Client's data	Tabular
Street addresses	Tabular

5.2 Integrated technology component

Phase two of this study is the integration of the RFID system into the remote sensing and GIS phase. First, a preliminary geospatial analysis involving remote sensing and GIS would have been carried out to identify the existing land use of the study area, suitable locations in the study area for waste bins at defined distances before the placement of RFID tag on the bins. Geo-coding of bins is done manually through field investigation to identify and validate the best locations proposed by the GIS software by using a GPS receiver. RFID tag is attached to each bin with different unique identification code (serial number) in different location [26] and [27] in their research reported that low frequency passive tags are usually recommended because they offer long-term low-cost solutions and are operational in extreme conditions resistant to environment hazards. For the purpose of real-time monitoring of the evacuation of MSW, a combination of devices (GPS, GPRS, weighted sensor and RFID reader) are mounted of the collection trucks which is linked to the available database of land use and digital maps of the area of interest that is residence in the control server. When these collection trucks are within the defined radius of any bin with a tag, the reader placed on the truck sends signal communicating with the tag to capture the tag's serial number which contains information about the bin and it relays the collected data to the control server in real time. Similarly, the locations of the bins are identified by a GPS device on the collection trucks which also serve as a way point for all the routes of the trucks in altitude, distance and time. Consequently, this transmits location data to the control server through GSM/GPRS network which can be viewed in real time on a display map in a GIS environment. Data collected from the tags are connected with a timestamp in which the type of bin and weight sensor mounted on waste collection truck monitors the weight of garbage collected for each bin, truck's identity, load description and customer information. This information is stored in the truck's on-board computer and later transferred to the control server for data processing or directly to a central computer. The control server receives information from the RFID reader and compares it with the reference information on each bin in the existing geodatabase. After data processing, it is transferred to the GIS terminal. The real-time information can be shared with clients through a web-based solution. The entire system used is a combination of RFID system, GPS module, and GPRS network which is connected to the internet Protocol(IP) – fixed control center. Fig. 3 is a typical picture of an RFID system in MSW management and monitoring.

Figure 3: RFID system in MSW management and monitoring;
Source: Author.

6 CONCLUSION

As seen in recent times, the use of space-based data and other forms of information and communication technologies (ICT) for providing solutions in environment-related problems has been a formal practice by developed countries. This study has developed a conceptual model which comprises geospatial techniques and integrated communication technologies for MSW management and monitoring in developing countries. The model demonstrates a unique capacity to improve the quality of environment in MSW collection, transportation and disposal which tends to save energy, time and cost with a very high efficiency and effectiveness. The adoption and utilization of this model will generate multiple socio-economic sustainability and opportunities in terms of job creation, revenue generation, eco-friendly society and, most importantly, identifying MSW as a resource out of place. The outcome of the utilization of this model through a well-coordinated synergy among stakeholders is expected to yield positive deliverables such as proper map updates on road network, truck routes for MSW collection, best location for waste bins and siting landfills, statistical data and updates on waste quantity in tonnes, subscribers information, waste characterization and identification codes in accordance to source of generation. Lastly, this study provides all stakeholders in the solid waste sector a decision support system in terms of budgetary, planning and contingency plan to build a sustainable platform to tackle both present and future MSW management issues.

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CASE STUDY

4.3 A GIS-based analysis for sanitary landfill sites in Abuja, Nigeria

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Abstract
The absence of sanitary landfill in Abuja, Nigeria has been a challenge that needs the full attention of the authorities. The improper disposal of municipal solid waste (MSW) on open land is a burden to the government due to the health implications and the socioeconomic issues associated with it. In order to mitigate environmental degradation, health risk concern and public vexation, the study aims at identifying suitable sites for MSW disposal in Abuja Municipal Area Council and Bwari area council of Abuja which meets global specification and standards. The integration of Geospatial data: Landsat-7ETM+, Nigeria Sat-X, ASTER-GDEM, base map, soil and geology maps and multi-criteria evaluation, was used to evaluate the relative importance of each criterion in the study. Each map layers were formed by using the spatial analysis potential of the ArcGIS10.1 software and final suitability map was created using the weighted overlay analysis. The results of the analysis identified six potential sites for sanitary landfill; however four out of the six sites were considered due to the land area size of the sites and its non-intersection with the Abuja land use plan. Also, results showed that none of the existing MSW disposal sites met the global standards considered. In view of the ecological and environmental challenges regarding MSW disposal sites in Abuja, this study shows that GIS is an effective tool in MSW management, which will assist decision makers to plan appropriately toward achieving an aesthetic, healthy and sustainable environment.

Keywords Dumpsite · GIS · Multi-criteria evaluation · Municipal solid waste · Sanitary landfill

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1 Introduction

Excessive generation of municipal solid waste (MSW) as a result of rapid population growth and urbanization has led to a major environmental concern. Saeed et al. (2008) reported that the generation of solid waste is directly proportional to population, industrialization, urbanization, changing lifestyle, food, habits and living standards of the people. One of the challenges confronting MSW management in most developing countries around the globe is the issue of improper siting of MSW disposal facility. Most of the existing solid waste disposal sites in developing countries are open dumping system because the technologies of proper sanitary landfill practice are not fully implemented (Matsufuji and Sinha 1990). However, in developed countries, proper landfills exist along with the proper construction and maintenance of the same (DOE/EIA 1999). Tchobanoglous et al. (1993) described dumpsites or landfills as a place designated for disposal of normally solid or semisolid materials, resulting from human and animal activities that are considered use- less, unwanted or hazardous. Improper MSW disposal in the society has led to the resistance and protest "Not in my backyard" NIMBY by inhabitants whose settlements are close to waste disposal sites. It is a known fact that the justification for NIMBY has largely been associated with environmental degradation and public health issues. The pattern of disposal of refuse and poor management practice by the authorities has led to an increase in the number of open dumps in most urban centers in Nigeria. In addition, Hauwa (2003) reported that heaps of solid waste continued to emerge in Nigerian cities on a daily basis; hence, sites have become fertile ground for breeding flies and other vectors which in effect became health hazards, obstructing traffic flow, causing environmental degradation and general unsightliness. Again, there have been pronouncements on effective waste management programs in the past but lacks the political will and implementation (Aderoju et al. 2015). Solid waste management in Nigeria has been challenged with ineffective col- lection technique, inadequate coverage of the collection routine and unlawful dumping of solid waste (Babayemi and Dauda 2009). At the international level, criteria with different degree of detail exist as a guideline for the optimum siting of landfills (Baban and Flannagan 1998). Land is a scarce and lucrative resource in Abuja and as a result (Oyinloye and Fasakin 2013) reported that landfill siting has become one of the problems confronting waste management planners due to the site requirements for its operation. Also, it is known fact that the quality of the environment has a direct impact on the value of housing (Shabana et al. 2015). Nevertheless, the damaging effect caused by indiscriminate dumpsites has raised a lot of concern among the residence in Abuja as a result of open and uncontrolled combustion of MSW which often leads to fire outbreaks and smoke threatening the people and their environs. Moreover, the odor from decomposing MSW in dumpsites alters the air quality, and street littering thereby leading to blockage of the drainage systems are common issues. Studies have shown that the selection of a suitable waste disposal site has its own complexity because it requires the evaluation of many different criteria and considerable expertise in diverse social and environmental fields such as soil science; engineering; hydro-geology; topography; land use; sociology; and economics (Chang et al. 2008; Nishanth et al. 2010). Thus, it is imperative that the regulations, constraints and land use of a particular environment must be considered before selecting a sanitary landfill site. For a proper landfill siting to be sustainable, it is essential to integrate a wide range of spatial variables that represent different factors to determine the location optimization (El-Fadel et al. 1995). Several researchers have used land use change assessment as an essential component of their methodology for environmental monitoring and management studies. For example, studies conducted by Ali and Nitivattananon (2012) and Ali et al. (2018) revealed that energy consumption data with land use change assessment were used to verify that the sources of CO_2 from major sectors of the economy have increased more than the car- bon sinks. Thus, it was concluded that the sinks (agriculture and vegetation) have reduced by more than half of its original size within a period of time. Currently, GIS has been adopted by researchers as a multidisciplinary tool that can be used to address socioeconomic and environmental issues. The use of Geographic Information Systems (GIS) as a tool for analysis in solid waste management has been of great advantage in recent times. Although, there are researches that focused on other important aspect of MSW management in the society, for instance Babayemi and Dauda (2009), focused on: the quantity and rate of solid waste generation in several cities in Nigeria; factors influencing the MSW generation; the MSW categories; collection and disposal pattern among others. Also, Nabegu 2011 revealed that based on the current solid waste generation and management practices in Nigeria, the waste sector contributes significantly to the greenhouse gas emissions of the nation and the world at large. In another study by Ali et al. (2013), benefit–cost analysis (BCA) was used to compare the best suitable technical solution for the recycling of green waste produced from Talaad Thai, Thailand. The result of the study shows that biogas production is of greater merit than compost as a result of its cost-effectiveness and sustainability. Taraves et al. (2011) utilized the combination of both the Analytical Hierarchy Process (AHP) and GIS to identify the best available locations for the siting of a municipal solid waste incineration plant in Santiago Island of Cape Verde. In addition, Ali et al. (2010) used a neoteric concept which involve the use of Social Health Technological Economic Financial Institutional Environmental (SHTEFIE) criteria to suggest an appropriate technology for the Thammasat hospital solid waste management. Consequently, the incineration technology emerged the better option as compared to sanitary landfill due to its cost-effectiveness, feasibility and sustainability. However, there are a number of suit- ability analysis studies that have been done on siting landfill/dumpsite using GIS techniques in different cities in Nigeria using World Bank criteria (see Table 2). For instance, Nwambuonmo and Mughele (2012) evaluated the existing landfill sites in Lagos, established the need for new dumpsites and proposed candidate landfill sites, using GIS with the World Bank criteria for siting a landfill. Most studies considering site suitability for sanitary landfills have its shortfalls due to the complexity of the land use; varying geology and soil types; hydrology and topography; and the dynamic settlement pattern in Nigeria. GIS began to be used for site selection or ranking by means of salient analysis found in a GIS (Jensen and Christensen 1986; Scott et al. 1989; Chang and Pires 2015). Also, GIS is used as a framework for mapping and displaying information about waste sites and processes (Wong and TenBroek 1989). GIS can simply be described as an informative system that collects, manages, analyses, manipulates and the retrieval of geographically referenced data (ESRI 1996).

The study aims at identifying suitable sites for MSW disposal in Abuja Municipal Area Council (AMAC) and Bwari area council of Abuja. Furthermore, the study intends to investigate the land use types in the study area; identify and map out the existing dumpsites; and find the most suitable sites for sanitary landfill. This study centered on only two local governments AMAC and Bwari area council of the Abuja (Fig. 1) due to their urban growth. In general, an efficient waste management practice yields great benefits, and thus, it forms an integral part of sustainable development of any society. The use of GIS in site suitability for waste management facilities goes a long way because space-based data are presently used globally to solve sustainable environmental issues for better decisions, planning, and solutions by the decision makers. This study, therefore, intends to develop a GIS-based concept for siting sanitary landfills in Abuja using more comprehensive criteria that takes into account the shortcoming of previous studies for sustainable development. Hence, it will be of great significance to identify suitable sites for sanitary landfills in order to meet the environmental, socioeconomic and health standards of the people.

2 Methodology

This approach focused on the role of GIS and multi-criteria evaluation (MCE) to attain at suitable locations for sanitary landfill in Abuja. The MCE was adopted from the Environmental Protection Agency (EPA) landfill siting standards to attain sustainable results. The important factors considered for siting a sanitary landfill are slope; land use; geology; soil data; roads; and water body/river. These criteria were generated in layers in a GIS environment, using the spatial analyst tool capabilities of the ArcGIS 10.1 software by ESRI. The optimal information from the EPA landfill siting criteria was used to establish safe distances away from a possible sanitary landfill and varying degree of suitability within each layer. Figure 2 shows the workflow diagram adopted for this study, and it displays the operations performed to achieve the results.

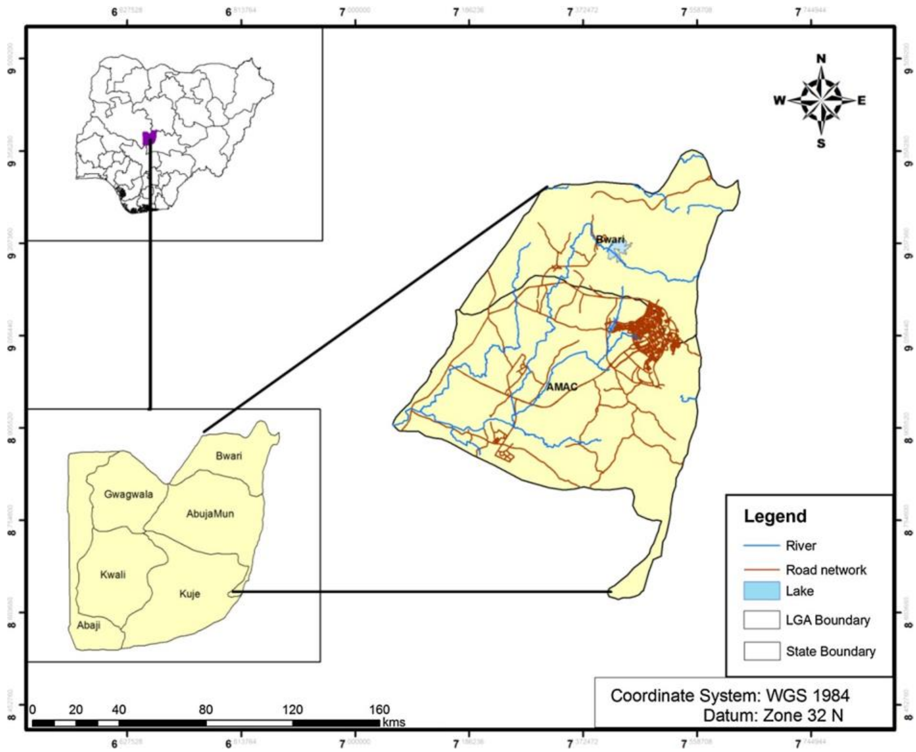


Fig. 1 Study area map

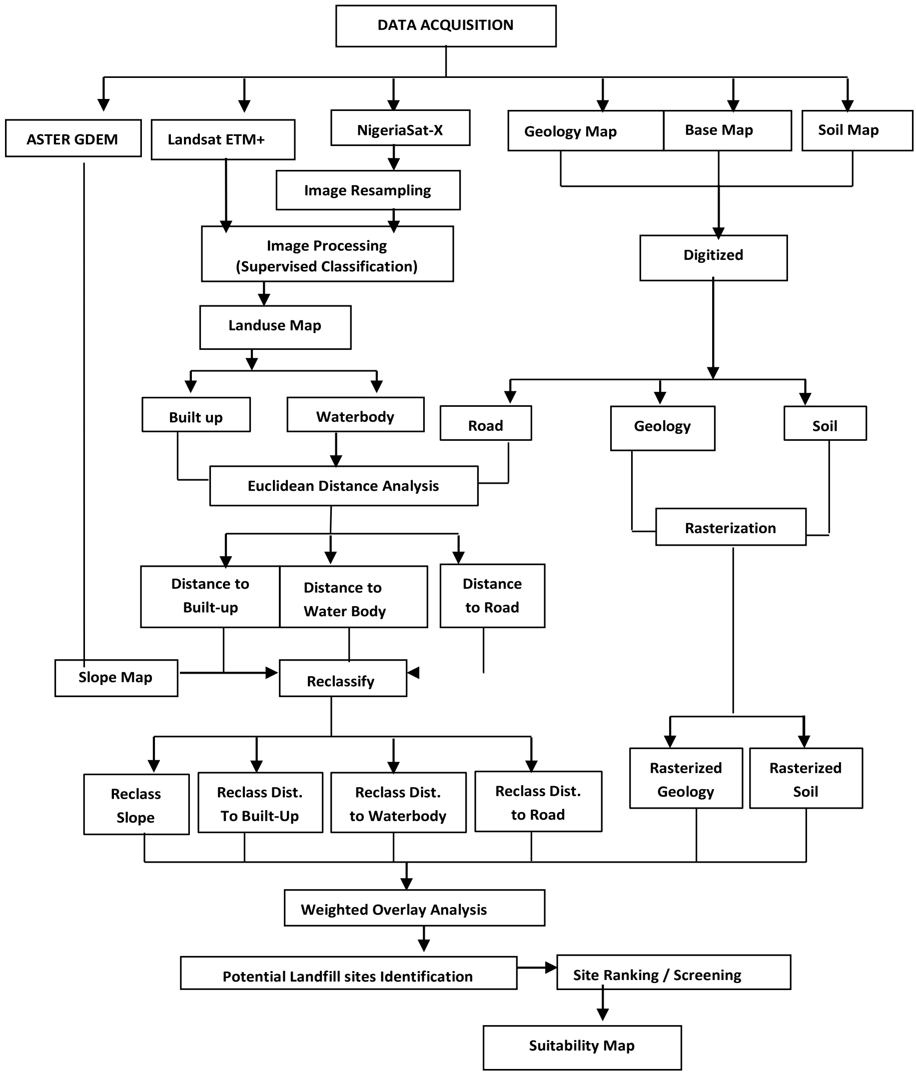


Fig. 2 Methodology workflow

2.1 Study Area

Abuja, the capital city of Nigeria is located in the center of Nigeria in the Federal Capital Territory (FCT) within latitude 7°25′N and 9°20′N of the equator and longitude 5°45′E and 7°39′E of the meridian. The Federal Capital Territory has a land area of 7753.85 km^2 square kilometers and a population of about 2,238,800 persons (NPC 2011). Abuja lies within the Guinea savannah vegetation belt and experiences two seasons (dry and wet). Abuja has two broad geological regions with each one having similar structural and lithological characteristics. These regions comprise the Precambrian basement complex and sedimentary rocks, which both have very strong influence on the morphological characteristics of the local soil

(Ola 2001). The rocks consist of Gnesis, Migmatites, Granites and Schist belt outcrops along the eastern margin of the FCT. The soil type in Abuja is predominantly Lixisols and can be described as the presence of a subsurface layer of accumulated kaolinitic clays which are also identified by the absence of an extensively leached layer below the surface horizon (Sonneveld 1997). Abuja experiences an average daily minimum and maximum temperature of 20.5 and 30.8 °C, respectively. This has its minimum in August and September and the highest in January–March. It has a mean rainfall and humidity of about 119.2 mm and 58.4%, respectively, with the highest in August and lowest between November and March, respectively.

2.2 Current status of MSW disposal sites in Abuja

The extent of MSW generated in Abuja is quite high as a result of the economic status and population density of the Federal Capital. It is unfortunate that regardless of the aim of the Abuja Master Plan as a model city to other cities in Nigeria, there is no existing sanitary landfill present. In Abuja, the MSW composition is a mix of degradable and non- degradable components. The agencies in charge of managing the MSW in Abuja is the Environmental Protection Board (AEPB), which takes in its jurisdiction to oversee all the waste in AMAC while the Environmental Protection Department of the Bwari area council headquarters has the same authorization as the AEPB to perform similar duties in Bwari area council. In order to improve solid waste management in the Abuja, a partnership between AEPB and a number of individual companies began in 2003. Hence, companies were allotted to various districts to collect and transport garbage to various disposal sites a number of times per week (Abubakar 2014). According to AEPB, there are four major disposal sites (Mpape, Gosa, Ajata and Kubwa) under its management. In 2013, Kadafa et al. reported that Mpape, Ajata and Kubwa disposal sites were opened in 1989, 1999 and 2004 but unfortunately all three were closed in 2005 based on problems associated with odors, air pollution and fire outbreaks from burning wastes at the site. In Mpape dumpsite, there has been seepage of leachate from the buried waste that flow to the surface, especially during raining season, which produces more leachate due to infiltration (Kadafa et al. 2013). However, there exists a private dumpsite (see Fig. 3) and some indiscriminate dumpsites in Kubwa other parts of Bwari area council. Presently, the MSW from the formal collection system in the various districts of the Federal Capital City, Abuja, is transported to a single dumpsite at Gosa (see Fig. 4).

Fig. 3 Kubwa Express private dumpsite

Fig. 4 Gosa dumpsite

2.3 Land use dynamics in Abuja, Nigeria

Abuja is growing at an exponential pace due to its rapid population growth; escalating socioeconomic activities; political activities; commercial and industrial activities; increasing urban growth as well as its environmental dynamism brought about rapid changes in the land use pattern of the city. The urbanization of Abuja also affects the surrounding towns and settlements by posing a threat to the limited available resources, thereby resulting in high cost of living (Ekoh et al. 2006). To understand the dynamics of patterns, processes and their interactions in heterogeneous rural and urban environment, one must be able to quantify accurately the spatial pattern of the land use and its temporal changes (Wu et al. 2000). It is evident that increasing population is simultaneous to land use growth, as a result, it alters the natural land cover of any society. Consequently, the quantity of MSW and emerging dump sites has been on the increase in Abuja.

2.4 Data used and data source

The data used for the study includes satellite imageries; Landsat-7 Enhanced Thematic Mapper Plus (Landsat-7 ETM+(2001)) and Nigeria Sat-X (2011) with a spatial resolution of 30 and 22 m. Also, the ASTER-Global Digital Elevation Model (ASTER-GDEM) of 30 m covering the study area was also used in the research to generate elevation and slope of the study area. The geological map was obtained from Nigeria Geological Surveys from which the geology of the study area was extracted. The soil type in the study area was extracted from the soil map of Nigeria, which its source is from the European Digital Archive of Soil Maps. NigeriaSat-2 imagery of the study area was used to verify the land use type within the study area. The coordinates of existing dump sites within the study area were acquired in decimal degrees through field investigation using a Trimble Global Positioning System (GPS). ASTER-GDEM was used for elevation and to generate slope of the terrain in the study area. Table 1 shows the summary of the data used information.

2.5 Siting criteria

One of the most important applications of GIS is the display and analysis of data to support the process of environmental decision making. To meet a specific objective, several criteria need to be evaluated and this method is referred to as multi-criteria evaluation (Carver 1991). The criteria highlighted in Tables 2 and 3 are the guidelines.

Table 1 Data use and data source

Data	Data type	Resolution	Data source	Year	Relevance
Landsat-7 ETM+	Secondary	30 m	GLCF	2001	For land use/land cover type classification
NigeriaSat-X	Secondary	22 m	NASRDA	2011	For land use/land cover type classification
NigeriaSat-2	Secondary	5 m	NASRDA	2013	Land use verification
ASTER-GDEM	Secondary	30 m	NASA; ASTER website	2011	For elevation and to generate slope
Abuja base map	Secondary	1:100,000	NASRDA	2014	For boundary, river and road extraction of the study area
Geological map	Secondary	1: 250,000	Nigerian Geological Survey Agency (NGSA)	2004	To extract the geological information within the study area
Soil map	Secondary	1:1,300,000	European Digital Archive of Soil Maps	1997	To extract the soil types within the study area
GPS coordinates	Primary		Field Investigation	2015	For coordinates of the existing solid waste dumpsites within the study area

Table 2 World Bank landfill site criteria 2004. *Source* World Bank (2004)

S/N	Criteria	Buffer zone
1	Surface water	500 m
2	Residential areas	250 m
3	Airport	3 km
4	Paved access roads	> 10 kmaccess
5	Access road	250 m
6	Protected forest	500 m

Table 3 Factor criteria table formulated from EPA landfill manual 2006 (Ireland). *Source* EPA (2006)

Criteria	Least suitable	Moderately suitable	Highly suitable
Distance to water body	160–480 m	480–960 m	> 960 m
Slope	10°–15°	5°–10°	0°–5°
Distance to road	> 2000 m	1000–2000 m	100–1000 m
Distance to built-up areas	300–500 m	500–800 m	> 800 m
Soil	–	Alisols	Nitisols
Geology	Quartzite	Migmatite-Gness complex	Charnock/Granite

Table 4 Used criteria. *Source* Adopted from EPA (2006)

S/N	Criteria	Suitability factors
1	Built-up areas	800 m away
2	Road network	1000 m away
3	Water body	1000 m away
4	Slope	0°–5°
5	Geology	Granite, Migmatite and Gnesis
6	Soil	Lixisols (similar to Nitisols due to clay accumulation contents)

and conditions set as standards by the World Bank and Environmental Protection Agency (EPA) for siting of sanitary landfills. The World Bank criteria for landfill siting have been widely used by researchers to determine the best location for dumpsites. This has also been adopted by most Nigerian federal and state ministry of environ- mental agencies to build their legislation for siting dumpsites or landfills in the nation. However, the World Bank criteria seem unrealistic in an unplanned and fast-growing urban city as we have in some parts of Nigeria. For this reason, the landfill siting criteria by the EPA (2006) was preferred in this study based on the flexibility and the range of conditions to ensure factor of safety and sustainable development. Hence, this study adopts the EPA criteria of 2006 in Table 4 to determine the most suitable site for the sanitary landfill facility.

2.6 Geospatial analysis

In this study, the spatial datasets used were projected to the coordinate system of the World Geodetic System (WGS) 1984, Universal Transverse Mercator (UTM) Zone 32°N. The GIS software, ArcGIS 10.1 was used to carry out the mapping and other geospatial analysis. In order to maintain constancy and orderliness of datasets during spatial analysis, datasets were established as thematic layers which were designed in a geo-database with shapefiles of features equally created. GIS analysis performed in this study includes slope analysis, Euclidean distance analysis, reclassification, digitizing, rasterization and weighted overlay. Image Resampling was carried out on the Nigeria Sat-X to the same resolution as the Landsat-7 ETM+ imagery to ensure uniformity. The resampling process calculates the new pixel values from the original digital pixel values in the uncorrected image. Nearest neighbor resampling uses the digital value from the pixel in the original image which is the nearest to the new pixel location in the corrected image. Similar bands/channels (Near Infra-Red, Red, and Green) of the two-satellite data were combined to yield a better visual sense of judgment in data interpretation. Supervised image classification was carried out on the Landsat-7 ETM+ and Nigeria Sat-X imageries with the maximum likelihood algorithm to derive the land use/land cover types using ERDAS Imagine 2014 application software. Also, a comparative analysis was carried out on the satellite imageries using a post-classification comparison technique. The images were classified independently using the supervised classification scheme in ERDAS imagine 2014 and compared with one another to identify possible changes in the land use/land cover within an epoch of 10 years (2001–2011). The slope of the study area was generated by carrying out slope analysis on the ASTER-GDEM to using the Spatial Analyst tool of the ArcGIS 10.1 software.

2.7 Euclidean distance analysis; reclassify; raster operation

The Euclidean distance analysis was carried out with measured safe distances (see Table 4) from the following land use of interest (built-up areas, water body and road network). The output of the analysis resulted to raster maps with radial distances from the land use of interest. The slope map generated and the Euclidean distance raster of built-up areas, road network and water body were reclassified and ranked from (1–10) which indicates from non-suitable to the highly suitable. Other factors such as the digitized geology and soil maps of the study area (AMAC and Bwari area council) were rasterized in order to perform the weighted overlay.

2.8 Weighted overlay method

The weighted suitability model was developed then ran in ArcGIS 10.1 software using the spatial analysis tool for sanitary landfill site suitability. Moreover, this is subject to a number of thematic layers and Multi-Criteria Evaluation adopted for the study. Weights deter- mine the level of significance of each criterion compared to the others, and accounts for the degree of compensation for each factor in the factor group (Gemitzi et al. 2006).The process converts data to numeric scales which is commonly called standardization (Voogd, 1983). The standardized factors are combined by means of weighted linear combination in which each factor is multiplied by a weight, with results being summed to arrive at a multi- criteria solution. Here, each individual raster cell is reclassified into units of suitability and multiplied by a weight to assign relative importance to each. Furthermore, adding them together to obtain the final weight, which serves as a suitability, value for every location on the map. The weighted overlay sum is a method that overlay several raster multiplying each by their given weight and summing them together (Nwosu and Pepple, 2016).

$$\text{For instance, Suitability}\,(S) = \Sigma wiXi \tag{1}$$

Equation (1) is interpreted by Eastman (2001) as; where *wi* = weight assigned to factor *i*, *Xi* = criterion score of factor *i*, S = Suitability index for each pixel in the map.

2.9 Assessment of existing dumpsites and standards

During the field investigation, the coordinates of existing dumpsites were obtained from the study area using a handheld Trimble GPS device through a field measurement approach. The coordinates for existing dumpsites collected during field investigation were tabulated into an excel sheet and then imported into the ArcGIS environment as a text file. It was later converted to shapefile under the same coordinate system and projection to actualize the location of these dumpsites in the study area. The points as a thematic layer were over- laid on the resultant sanitary landfill suitability map using GIS and the multi-criteria analysis. This was to validate whether any of the existing dumpsites location within the study area is in accordance with the global standards. Table 5 shows the coordinates (in decimal degrees) of the exiting dumpsites in AMAC and Bwari area council.

3 Results and discussion

The population data for all the local government area (LGA) councils in Abuja for the year 2001 and 2011 are displayed in Table 6. This is a clear indication that the abrupt increase in population is due to the migration of people in search for job opportunities because of the socioeconomic activities; political activities; commercial and industrial activities in Abuja.

3.1 Analysis and discussion of results

In the analysis of the results, all data map layers in vector format were rasterized. Raster data are made up of picture elements (pixels) which is in the form of a grid (rows and columns) whereby each pixel has a digital number (brightness value) that ranges between

Table 5 Location of dumpsites in AMAC & Bwari Area Council

S/N –	Location name	Longitude	Latitude
1	Agwa-Mango Mpape	7.372222	9.041111
2	Gossa	7.339722	9.031944
3	Dutse Baupma	7.381667	9.178333
4	Kubwa Express	7.335556	9.143611
5	Kubwa FHA	7.357778	9.161389
6	Mpape Village	7.501179	9.146497
7	Karshi	7.560162	9.012345
8	Karu/Nyayan	7.526823	8.840921

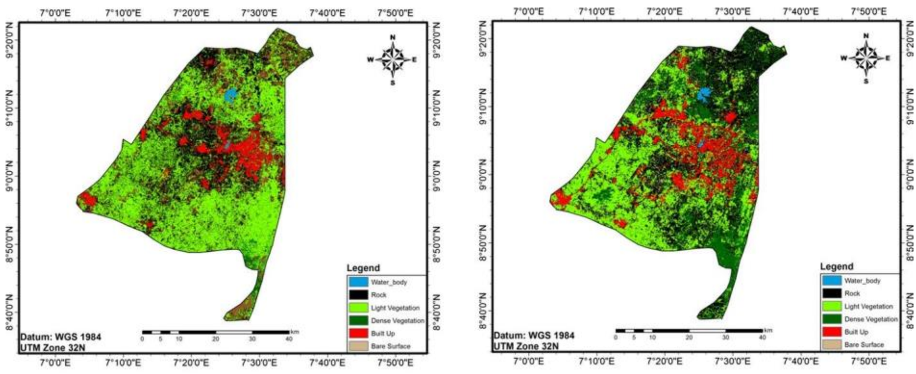
Table 6 Abuja population data. *Source* NPC (2011)

Local Government Area	2001	2011
Bwari	136,330	365,000
AMAC	467,140	1,235,880
Abaji	35,067	93,360
Gwagwalada	94,662	252,520
Kuje	58,422	154,800
Kwali	52,112	137,190
Total	843,733	2,238,800

(0–255), thus representing information. The accuracy assessment of the classified images was estimated at 87 and 85%, respectively. The land use maps displayed in Fig. 5 were used to assess the extent of urban expansion in the study area from the year 2001 to 2011. According to Taraves et al. (2011), the land use represents a degree of economic activities and population density associated with the area under study.

Table 7 shows the land use/land cover dynamics in AMAC and Bwari area council within a period of 10 years. The result in Table 7 shows that Light Vegetation and Bare Surface have reduced drastically by 25.59 and 30.885%, respectively. However, the built- up represents the degree of urbanization and has increased by 64.504% between the years 2001 and 2011. Also, the dense vegetation had increased to about 246.547% of its original size due to the forest area preservation initiative and privately owned mechanized farming with canopy trees while water body reduced by 8.105% due to climate change-related issues. Figure 6 displayed the land use change statistics of the study area while Fig. 7 shows the built-up maps indicating the before (2001) and after (2011).

Figure 7 shows that urbanization grew by 64.504%, which is about 91.684786 km^2 by land mass between the years 2001 and 2011 in the study area. Consequently, it is an indication of a possible rise in the quantity of MSW generation due to the increasing population and human activities present. Figure 8 displayed the statistical data on the trend of the quantity of disposed MSW in AMAC between 2010 and 2011. The data cover areas under the supervision and operation of the AEPB and other private waste management firms.



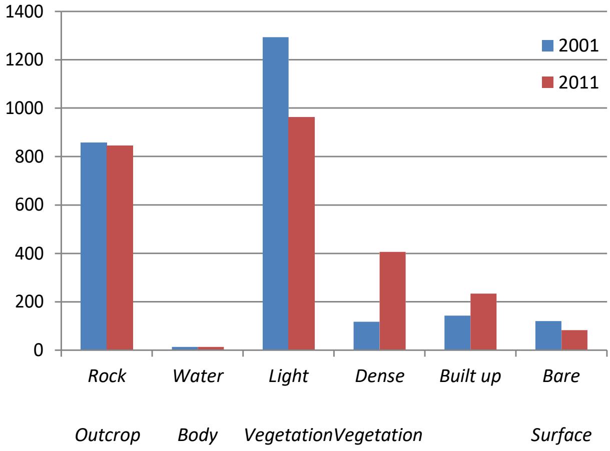
(a) (b)

Fig. 5 AMAC & Bwari land use map: **a** 2001; **b** 2011

Table 7 Land use/land cover statistics

Land Use	2001(km^2)	2011(km^2)	Change (km^2)	% Change
Rock outcrop	857.358831	844.912252	− 12.446579	− 1.4517
Water body	13.695730	12.585729	− 1.1100001	− 8.105
Light vegetation	1293.537802	962.406069	− 331.131733	− 25.59
Dense vegetation	117.198193	407.256823	288.948630	246.547
Built-up	142.137140	233.821926	− 91.684786	64.504
Bare surface	119.671146	82.710542	− 36.960604	− 30.885
Total	2543.598842	2543.693341		

Fig. 6 Land use statistics of AMAC & Bwari Area Council



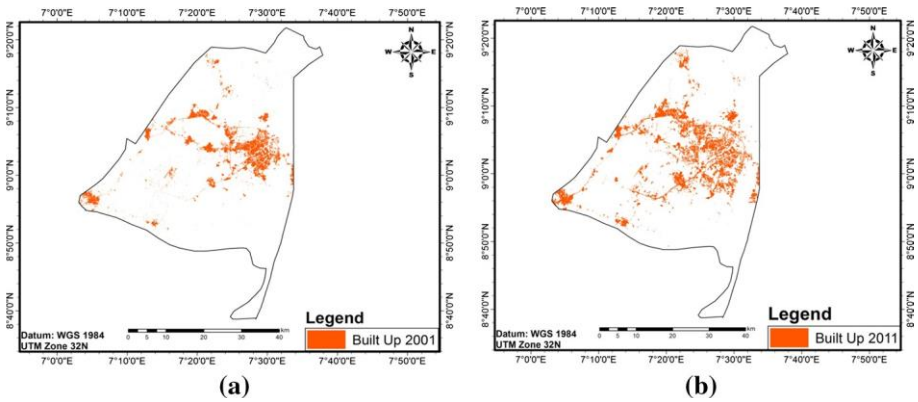


Fig. 7 AMAC & Bwari Built-up Map: **a** 2001; **b** 2011

registered under it. It is quite unfortunate that due to the inconsistencies of the services rendered and lack of data for Bwari area council, adequate data were not accessible for MSW management. Moreover, from the year 2010 to 2011, there was a decrease in the quantity

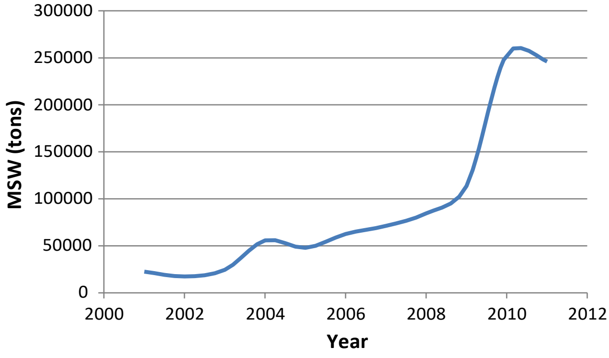


Fig. 8 Trend of MSW quantity (tons) from 2001 to 2011 in AMAC, Abuja. *Source* AEPB (2015)

of MSW generated (see Fig. 8) as a result of the widespread practice of material recovery by scavengers from waste dumps for their livelihood.

3.1.1 Euclidean distance analysis result

The Euclidean distance analysis was applied to attain a safe distance away from sanitary landfill in the study area, according to the above-mentioned criteria in Table 4. In this analysis, the specific conditions are:

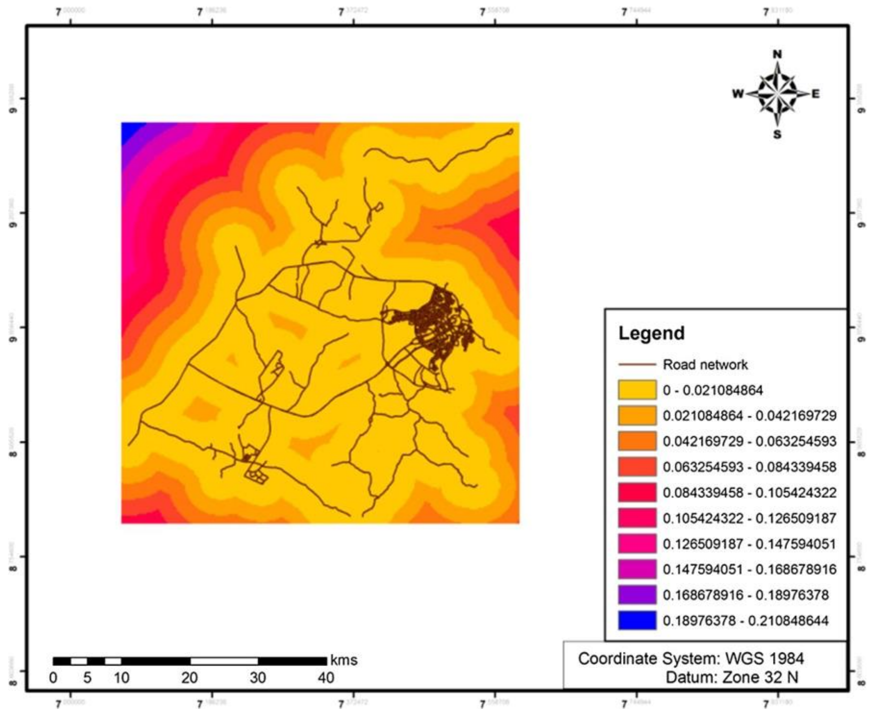


Fig. 9 Euclidean distance analysis for road map layer

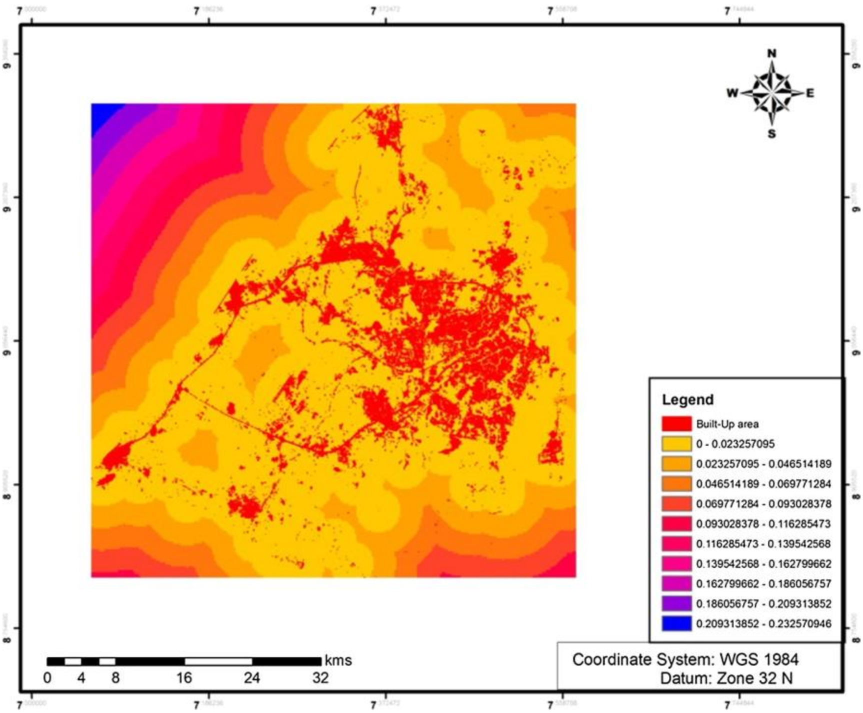


Fig. 10 Euclidean distance analysis for built-up area map layer

3.1.1.1 Landfill should be sited at 800 m away from built-up areas

This is vital because the clustered urbanized and unplanned development in AMAC and Bwari area council has led to the complexity of the building pattern. Nevertheless, a desirable 800 m radial distance away from urban centers and population settlements was employed for site suitability analysis of sanitary landfills. Furthermore, the health and sanitation risk of the inhabitants of the study is paramount; hence, 800 m safe distance away from built- up areas as shown in (Fig. 10) is suitable to site a sanitary landfill facility.

3.1.1.2 Landfill should be sited 1000 m away from the water body/river

This is significant because siting a landfill close to a water body has a great health implication on any society. The heterogeneous nature of the MSW contains toxic substances that can impair human and animal lives. Most of the running rivers in the study area are used for rural water supply and agricultural purposes. For instance, the lower Usman dam in the Bwari area council and the Jabi Lake in AMAC are feed from these rivers for rural water supply of the city. Therefore, a safe distance of 1000 m away from water body is suitable for siting a landfill in order to minimize possible contaminant from landfill leaching, seepage, and runoff to the rivers and streams (see Fig. 11).

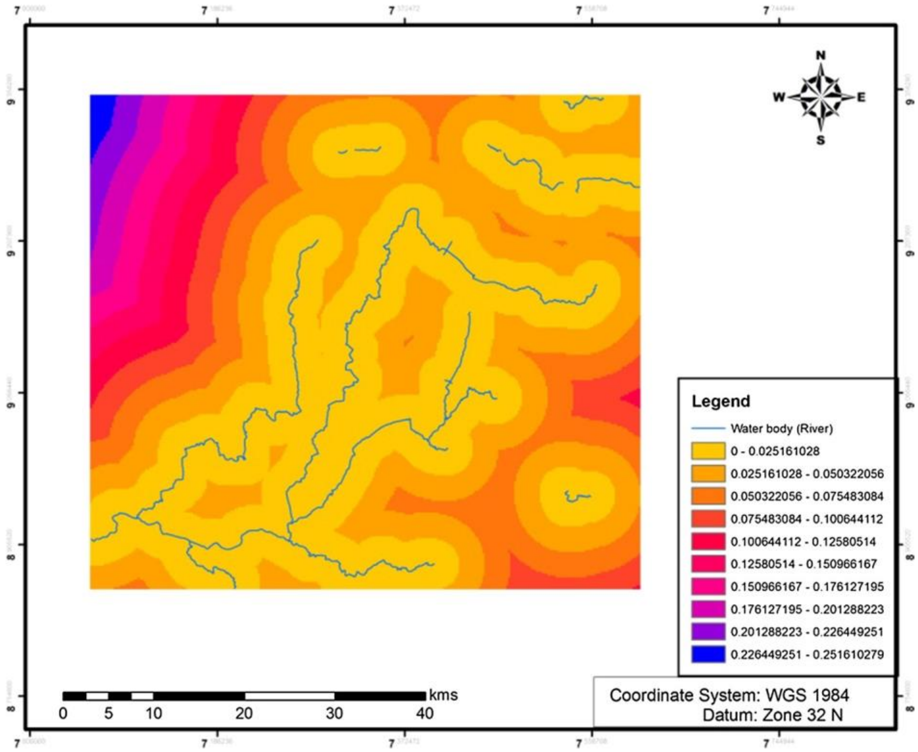


Fig. 11 Euclidean distance analysis of river map layer

3.1.1.3 Landfill should be sited 1000 m away from a road network

It is imperative to have close proximity to the source of generation of MSW while siting a sanitary land- fill because, it gives a lower long-term economic cost, since the lengths of hauling the waste are decreased and are also more economically suitable (Baban and Flannagan 1998). However, Zeiss and Lefsrud (1995) reported that landfill facility development on/too close to existing road or rail network would hinder transportation and may have an impact on tourism in the region. Therefore, a reasonable and safe distance of 1000 m away from road networks for the siting of a sanitary landfill (see Figs. 9 and 16) is ideal because the travel time of collection trucks from waste collection points to landfill location should be accessible within a short distance without disrupting the commuters on the road. Figures 9, 10 and 11 show the Euclidean distance analysis maps for the study area.

3.1.2 Reclassification analysis result

Figures 12, 13 and 14 are the reclassify raster maps of the Euclidean distance analysis. Built-up areas, water body/river, and road networks are ranked with numeric values between the range of (10–1), representing the criteria employed to determine the most

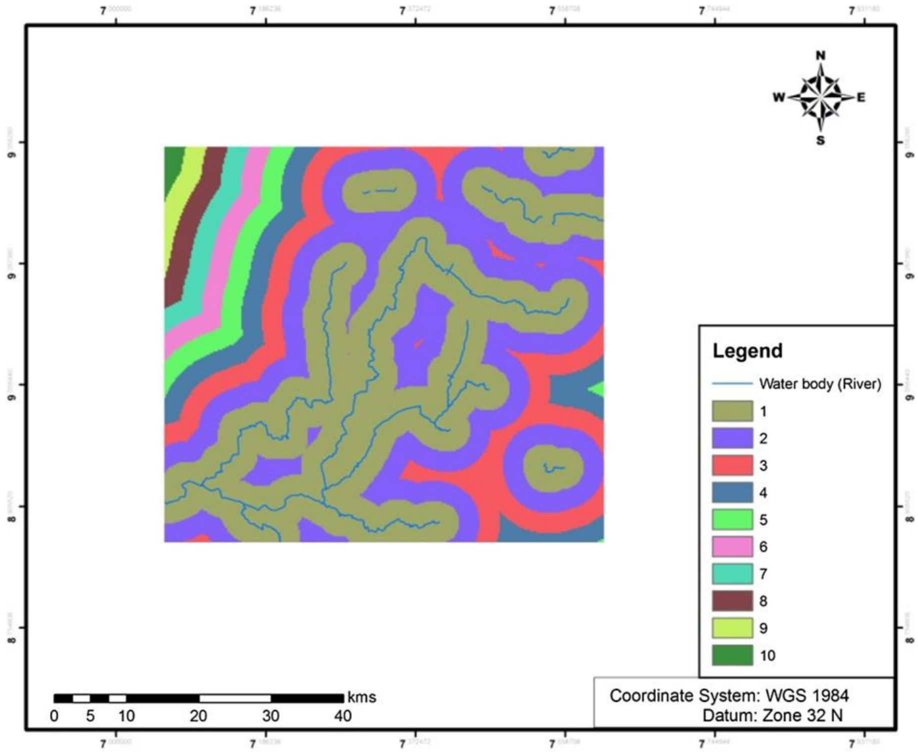


Fig. 12 Reclassified river map

suitable location for a sanitary landfill. This study shows that safe distance played a very significant role in the siting of sanitary landfills in the study area after different land use types were considered. Again, the terrain plays an important role in the siting of a sanitary landfill since steep terrains are not appropriate for hosting landfills (Issa and AL-Shehhi 2012). The risk of runoff and leachate from landfill is associated with the slope of terrain. Hence, this study employed slope between the range of 0°–5° as the best suitable option to enhance low construction cost and mitigate the adverse environmental impact. Therefore, the slope map layer was reclassified at a range of (1–10) because the lesser the steepness of the terrain the more suitable the location for a sanitary landfill (Fig. 15).

3.1.3 Geology and soil of the site

It is imperative to consider the characteristics of the soil and the geology of the terrain before siting a sanitary landfill facility. The rock types in the study area fall within the region of granite, gnesis and migmatites which is suitable for siting a sanitary landfill facility. In addition, the soil type (Lixisols) present in the study area has high clay content which is characterized by its high water retaining capacity, thus, preventing leachate and the percolation of contaminants into ground and surface water sources. Studies by (Atkinson et al.

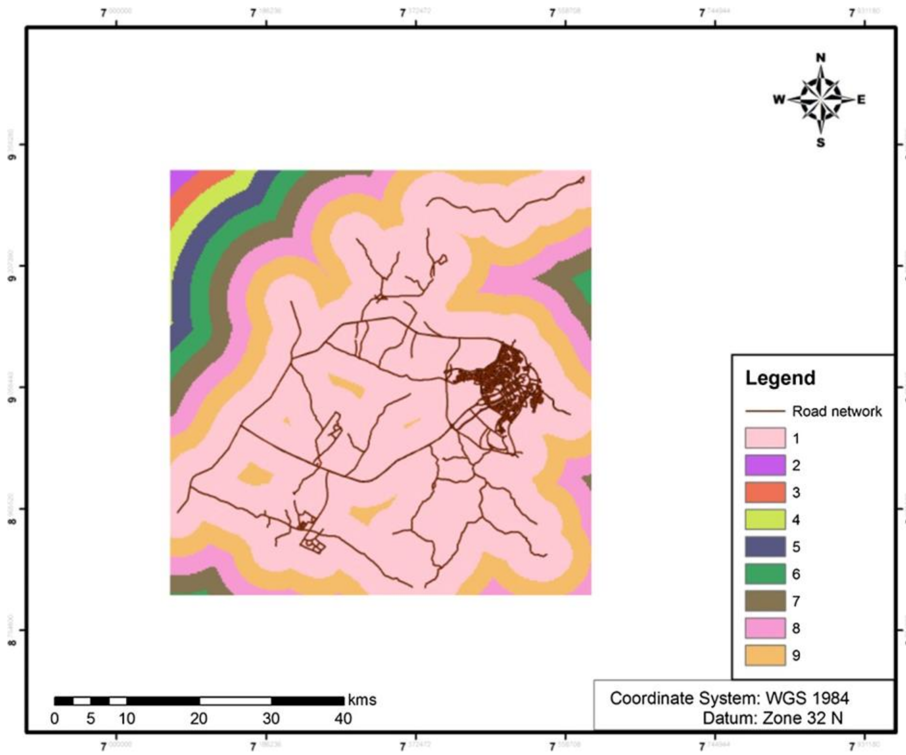


Fig. 13 Reclassified road map

1995; Dorhofer and Siebert 1998) showed that low hydraulic conductivity, low effective porosity, permeability, high retention of hazardous solutes and workability are important soil considerations in siting a landfill facility. The geology and soil maps (raster) of AMAC and Bwari area council were utilized with other rasterized maps (Fig. 2), in the ArcGIS environment to create the landfill suitability map (Fig. 16).

3.1.4 Site Suitability Analysis Result

All the reclassified and rasterized map layers were overlaid using the weighted overlay method to create a single map showing its degree of suitability for the sanitary landfill site. Figure 16 shows the sanitary landfill suitability map for AMAC and Bwari area council, Abuja through which it identifies four main categories in the analysis which are: highly suitable (best choice); moderately suitable (alternative choice); least suit- able (bad choice); and no suitable (restricted). The non-suitable sites are the areas reserved for allocated for residential estates, industrial layout, mechanized farming and many more according to the Abuja master plan. In Fig. 16, six sites were identified as highly suitable for sanitary landfill, but only four sites were chosen due to land size. In

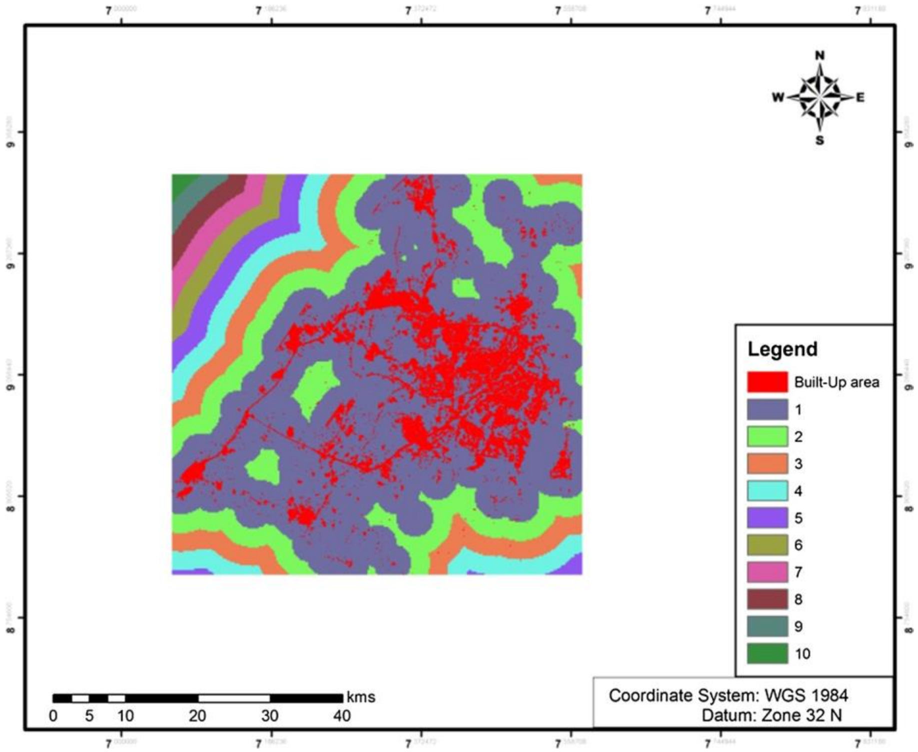


Fig. 14 Reclassified built-up map

addition, the Bwari area council has three identified sites while AMAC has one selected for the suitability of sanitary landfill sites. The coordinates of the existing MSW dump- sites collected during field investigation were imported into the ArcGIS environment in a text format and converted into a shapefile. The shapefile of the existing MSW dump- sites was overlaid on the sanitary landfill suitability map to see if the existing dump sites intersect with the identified suitable sites. However, the displayed map in (Fig. 17) indicated that only one (Karu/Nyayan dumpsite) was located on the least suitable site environs whereas the other six were located on non-suitable sites based on the above outlined criteria.

4 Conclusions

It is essential that all the states in Nigeria should adopt a much hygienic method of siting a municipal waste disposal facility by adhering to the global standards and requirements. This study demonstrates the capabilities of geospatial technology with the aid of spatial and non-spatial data to address the selection of a suitable site for a sanitary landfill facility. An integration GIS and MCE is a comprehensive, justifiable and efficient approach in

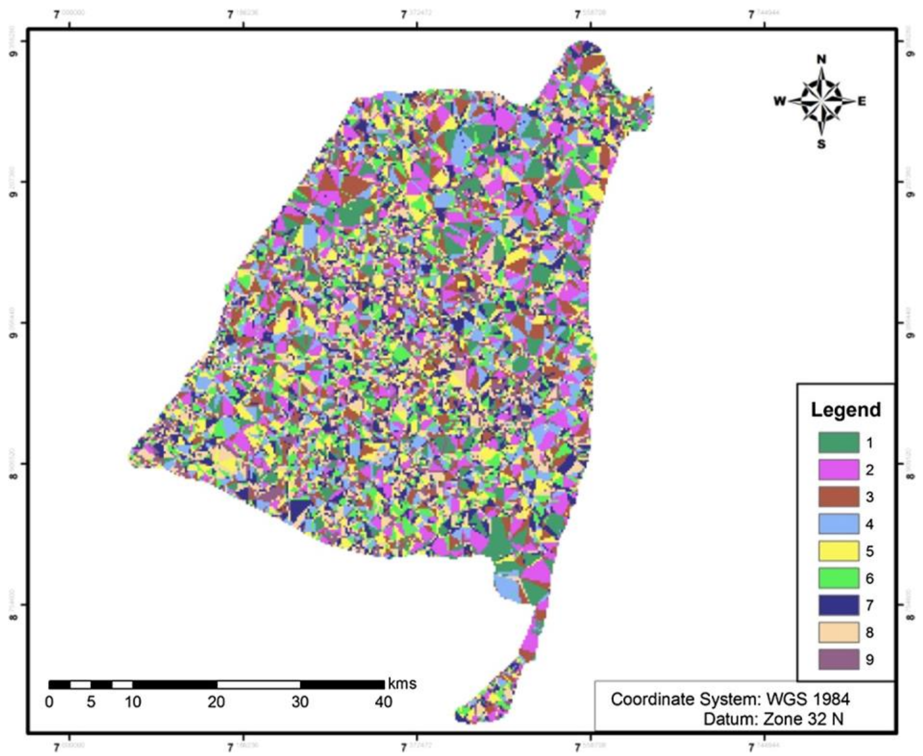


Fig. 15 Reclassified slope map

locating suitable sites for a sanitary landfill. The EPA (2006) manual for siting a landfill was adopted to produce an outstanding results used in various spatial analyses (Euclidean distance analysis, rasterization, reclassification and weighted overlay approach) of the GIS software (ArcGIS 10.1) to generate a suitability map for a sanitary landfill site. Also, a land use/landcover map of AMAC and Bwari area council was done whereby land use types were identified and the built-up map was produced to see the extent of urban growth in AMAC and Bwari area council over a period of 10 years. Weighted overlay analysis was assigned to establish detailed suitability ranking. The weighted overlay was done using an equal level of influence for all the factors in the GIS environment to determine suitable sanitary landfill sites. The result of this analysis displayed (see Fig. 16) is suitable areas for sanitary landfill sites which are identified as highly, moderately, least and non-suitable sites. Six sites were identified as highly suitable for sanitary landfill facility, but only four were preferred due to land size availability and other sustainable conditions with no inter- section with sensitive land use. Nevertheless, three out of the identified sites are located in Bwari area council and one in AMAC were identified and selected. Also, it was deduced from Fig. 17 that only one (Karu/Nyayan dumpsite) out of the seven existing dumpsites is located in the east suitable site environs while others are located on non-suitable areas.

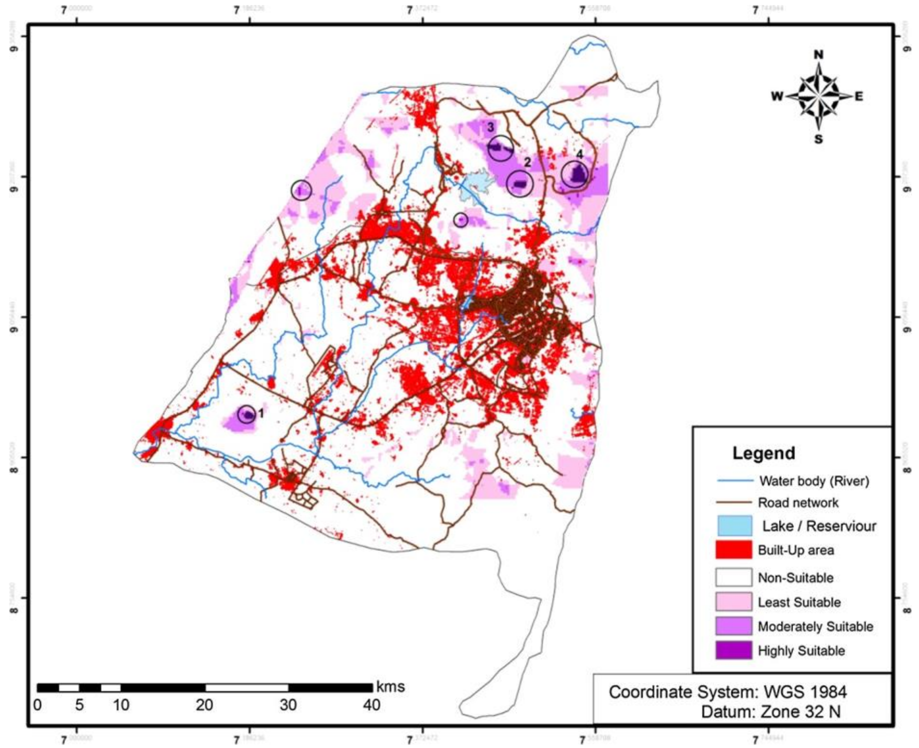


Fig. 16 Landfill site suitability map

The approach adopted in this study can be used as a decision support tool for urban planners and decision makers to make sustainable choices in selecting suitable sites for sanitary landfill facilities.

Hence, it is highly recommended that a well-defined environmental framework for solid waste management of the society should be integrated in the environmental planning and policies. Also, the solid waste management program structure should be standard, flexible and acceptable, in a way that the inhabitants of the society can support and be part of the implementation process. On-site validation of identified potential landfill suitability sites is essential because series of ground-based tests should be carried out for the protection of ground and surface water sources. The government, through public private partnership (PPP), should embark on building transfer stations on moderately suitable sites to ease operational costs for MSW collection and transportation. Again, town planning regulations should be emphasized and enforced in such a way that settlements, farming and other unlawful activities are not found in buffer zones to suitable sanitary landfill sites. Furthermore, the exploits of this research are also suitable for a possible landfill gas recovery system (LFGRS) for electrical power generation under the municipal waste to energy initiative. Stakeholders in the public and private sectors should support and explore geospatial technologies potentials to build a spatial database for the solid waste management sector.

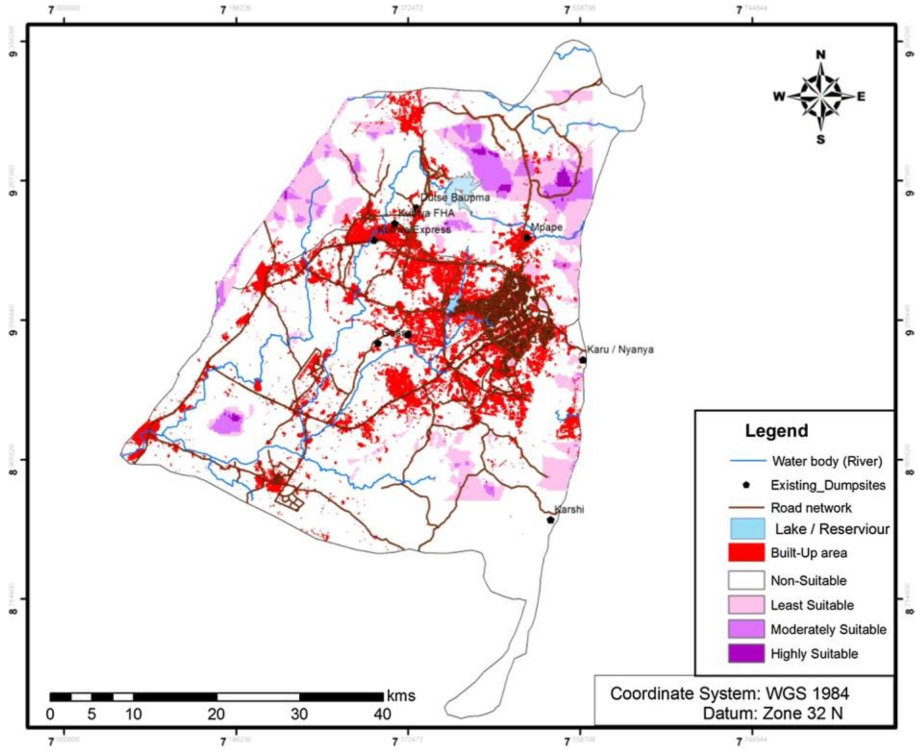


Fig. 17 Existing dumpsites map

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5.

Evaluate the calorific potentials of MSW streams using the empirical models (physical, chemical, and proximate) analysis and; Establish possible relationship for the power generation potential of MSW in Abuja, Nigeria and Porto, Portugal through a comparative method.

5.1 Introduction

The electricity supply situation in Nigeria has led to hunting for an alternative solution to meet the demand of the people for domestic and commercial use. Nevertheless, the global concern on the depletion of the non-renewable energy sources has led to the development of different techniques to harness energy in various forms. In Nigeria, the harnessing of renewable energies such as hydro, solar, and wind is likely to be hindered by the project cost, varying seasons of the year, as well as the location. Therefore, this study explored Waste to Energy (WTE) option as an alternative energy source whereby the utilization of MSW as fuel is likely to be the supplementary solution to the electrical power supply crisis in Nigeria. However, studies have shown that the incineration of MSW with energy recovery significantly reduces quantity of MSW to a bare minimum depending on the waste characteristics and the technology adopted. The WTE option is likely to reduce the number of landfills / dumpsites which has the tendency of reducing the pressure on land resources in cities as well as the pollution of the environment.

Therefore, it will be a great significance to utilize the MSW generated in major cities and rural towns in Nigeria as a resource for electrical power generation. The articles in this chapter include: (Aderoju et al. 2017), tried to justify the need for WTE as a reliable concept to close the gap of erratic supply in Nigeria. The methodology of assessing the energy potential in the combustible MSW was discussed in (Aderoju and Dias, 2018). Furthermore, the power generation potential (Q_{gp}) was estimated and compared for the combustibles for Abuja and Porto (Aderoju et al. 2019).

5.2 Assessment of Renewable Energy Sources & Municipal Solid Waste for Sustainable Power Generation in Nigeria

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Abstract. The demand for Energy in most Sub-Saharan African countries has become unimaginable despite its high potential of natural and renewable resources. The deficit has impeded the regions' economic growth and sustainability. Nigeria as a nation is blessed with fossil fuels, abundant sunlight, hydro, wind and many among others, but the energy output to its population (185 million) remains less than 4000 MW. Currently, the clamour for an alternative but renewable energy source is the demand of the globe but it is quite expensive to achieve the yield that meets the Nigeria demand. Hence, this study aims at identifying and mapping out various regions with renewable energy potentials. The study also considers municipal solid waste as a consistent and available resource for power generation. Furthermore, this study examines the drawbacks inhibiting the inability to harness these renewable, energy generating potentials in full capacity. The study will enable the authorities and other stakeholders to invest and plan on providing a sustainable energy for the people.

1. Introduction

Energy, as a major driver of global development is accompanied with its own shortcomings having fossil fuels as its conventional energy source which has contributed to the degrading environment as well as the socioeconomic effect associated with it. However, the increasing clamour for energy and satisfying it with a combination of conventional and renewable resources is a huge challenge [1]. Energy demand in Sub-Saharan Africa grew by around 45% from 2000 to 2012, but accounts for only 4% of global demand despite being home to 13% of the global population [2]. According to the UN Framework Convention on Climate Change (the Kyoto protocol), the developed countries agreed to reduce the emission of greenhouse gas to 1990 emission level [3]. Hence, climate change and other negative effects of using fossil fuels for power production, along with a growing demand for energy coupled with concerns over energy security, are driving the expansion of renewable sources of energy [4]. Sustainable development within a society requires a supply of energy resources that, in the long term, is readily and sustainably available at reasonable cost and can be utilized for all required tasks without causing negative societal impacts [5]. International climate negotiations have long pitted developing countries (focused on providing access to affordable energy to their populations) against developed countries, responsible for most of the greenhouse gases emitted to date but leading the shift to greener energy sources [6]. Hence, Renewable Energy (RE) in simple terms can be described as the obtainable energies from natural sources that are constantly replenished. With RE technologies, countries can meet their policy goals to secure, reliable and affordable energy to expand electricity access and promote development [7]. Globally, the call for renewable energy sources for a sustainable power in an eco-friendly manner is one of the major goals of the UNFCCC, IPCC and the EU among others. The RE sources in Nigeria are solar; hydro; bioenergy and wind are in abundance to be harnessed in full capacity to its electric power supply issue. Currently, the utilization of Municipal Solid Waste (MSW) as a biogenic form of renewable energy source for power generation is on the rise globally. Nigeria as a nation is blessed with fossil fuels, abundant sunlight, hydro, wind and many among others, however the energy output to its population (185 million) remains less than 4000 MW. Presently, the sporadic power supply in Nigeria has severely impeded the socioeconomic growth of the nation. Seasonal variation, lack of maintenance and inabilities to recent technologies has hindered the power output from the hydropower stations in Nigeria. Also, the inadequate supplies of natural gas due technical faults and sabotage hinders continuous energy production from thermal power facilities. Hence, this study aims at identifying and mapping out various regions with renewable energy potentials in Nigeria. The study also considers MSW as a consistent and available resource for power generation. Developing the RE sector in Nigeria would be a viable opportunity to salvage our degrading environment as well as providing a sustainable electric power supply to the people for socioeconomic growth.

2. Methodology

The methodology employed in this study aims to identify the available renewable energy sources and display it on maps. The used data sets are Nigerian State boundary map; minor and major river maps; Population data; Settlement map; Dam data and Hydro-electric facility data were obtained from the National Space Research & Development Agency (NASRDA) Abuja, Nigeria. Also, a 40-year available average wind data (1968 − 2007) from [8] was adopted and displayed on a map. Solar potential sites map was reproduced from solar irradiation data for Nigeria on the solargis website [9]. The use of geospatial software (ArcGIS 10.2) was used to carry out the mapping of the potential sites for renewable energy resource for electricity.

2.1. Study Area

Nigeria is a country located in the western part of the African continent which lies between the latitudes 5^0 N and 15^0 N and longitudes 5^0 E and 15^0 E and a landmass of approximately 924,000 km^2 [10]. It is blessed with many natural resources like crude oil, natural gas, limestone, gold and as many among others. Also, Nigeria has an immense potential of hydropower generation because of two great rivers (Rivers Niger and Benue) entering from the Northeast and Northwest, and with an access to 840 km coastline in the Southern part of the country [11]. The southern part of Nigeria lies on the coastline hence its tidal power potential can be utilized for power generation. However, the northern part of Nigeria is close to the Sahara region, hence it tends to experience a lot of sunlight and medium winds for a considerable electrical power generation. The abundance of biomass such as MSW among others, can be utilized as a resource for electrical power generation in Nigeria.

2.2. Hydropower

Hydropower is the largest renewable energy source, and it produces around 16% of the world's electricity and over four-fifths of the world's renewable electricity [7]. Hydropower in Nigeria currently accounts for about 19% of the total installed commercial electric power capacity. Also, the overall large-scale potential (exploitable) is more than 18,600 MW but unfortunately, just about 19% is currently tapped [12]. Hydropower can be described as a RE source that utilizes the energy of a fast- moving water or falling water channeled through a water turbine for the generation of electric power. In recent studies, hydropower potential sites are distributed in 12 Nigerian states and in the river basins. However, Small Hydro Power (SHP) potential sites exist in virtually all parts of Nigeria and there are over 278 unexploited sites with total potentials of 734.3 MW [13]. Small hydropower projects are generally considered to be more environmentally favourable than both large hydro and fossil fuel powered plants because they do not involve serious deforestation, rehabilitation and submergence [14]. At the moment, the large-scale operational hydro-electric power facilities in Nigeria are; Kanji, Jebba, and Shiroro respectively. However, the shift of attention to the use of fossil fuel for power generation contributed to the decay of theses hydropower facilities as a result, the extent of their output is below the installed capacity [15]. Generally, hydropower is the most flexible source of power generation available and is capable of responding to demand fluctuations in minutes, delivering base-load power and, when a reservoir is present, storing electricity over weeks, months, seasons or even years [16]. Furthermore, tidal power is another form of hydropower that is unpopular. The use of tidal power can be extracted from moon-gravity powered tides by locating a water turbine in a tidal current for the purpose of generating electric power supply [17]. The southern part of Nigeria has a coastline of about 840 km and its proximity to the Gulf of Guinea can be utilized by harnessing its tidal power potential. The concept of power generation in tidal power is like hydro power generation by extracting energy from a difference in hydrostatic head which occurs from rising and falling tides. However, tidal power is not a common technology because of the financial cost implications and other constraints, which should be examined before embarking on such project. The figure 1 shows the hydropower potential in Nigeria which comprises of rivers, coastline, hydropower stations, and dams for proposed power generation, irrigation, and for water supply purposes.

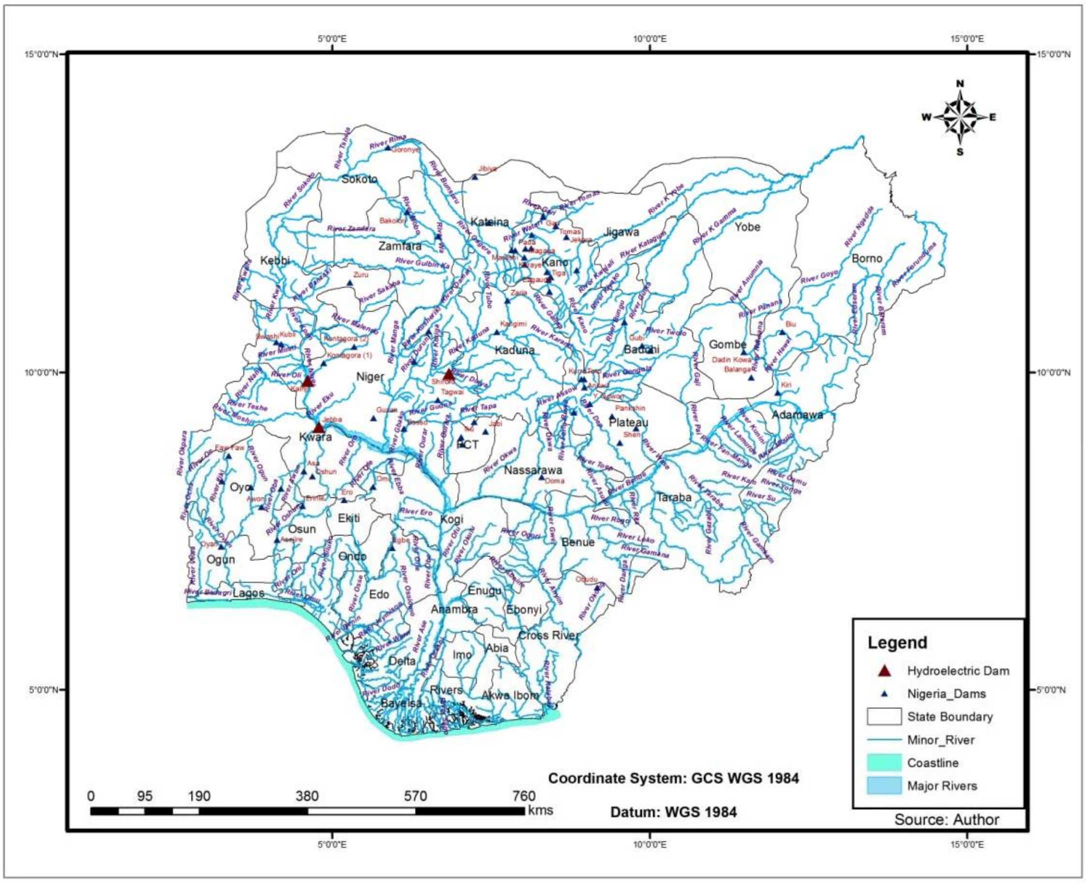

Figure 1. Hydropower potential Map

2.3. Solar Energy

The geographical location of Nigeria lies in the equatorial region, which is an advantage for receiving abundant solar energy, hence it could be harnessed daily in full capacity for electrical power generation. Solar power can be simply described as the solar radiation from the sun to the earth surface which converts its energy directly into heat or electricity. It was reported in [18] that the annual average daily solar radiation in Nigeria is about 5.25 kW h/m^2/day which varies between 3.5 kWh / m^2 / day at the coastal areas and 7 kWh / m^2 / day at the northern boundary. According to [19], there is a possibility to generate 1850 ×10^3 GWh of solar electricity per year which is over 100 times the current grid electricity consumption level in Nigeria. An alternative energy source (solar) in the rural areas for socioeconomic development, eco-friendly and better quality of life can promote poverty alleviation in Nigeria. Generally, the two main types of solar energy systems are currently the solar-thermal conversion and solar electric (photovoltaic) conversion. The most commonly available in Nigeria is the photovoltaic conversion which uses silicon panels that generate an electrical current when light shines upon it. The average amount of sunshine hours all over Nigeria varies between 4 - 7 hours daily [20]. Figure 2 shows the solar irradiation in Nigeria and delineates the areas of higher intensity suitable for solar power which shows that the northern part of Nigeria is the most suitable sites for large scale solar farms.

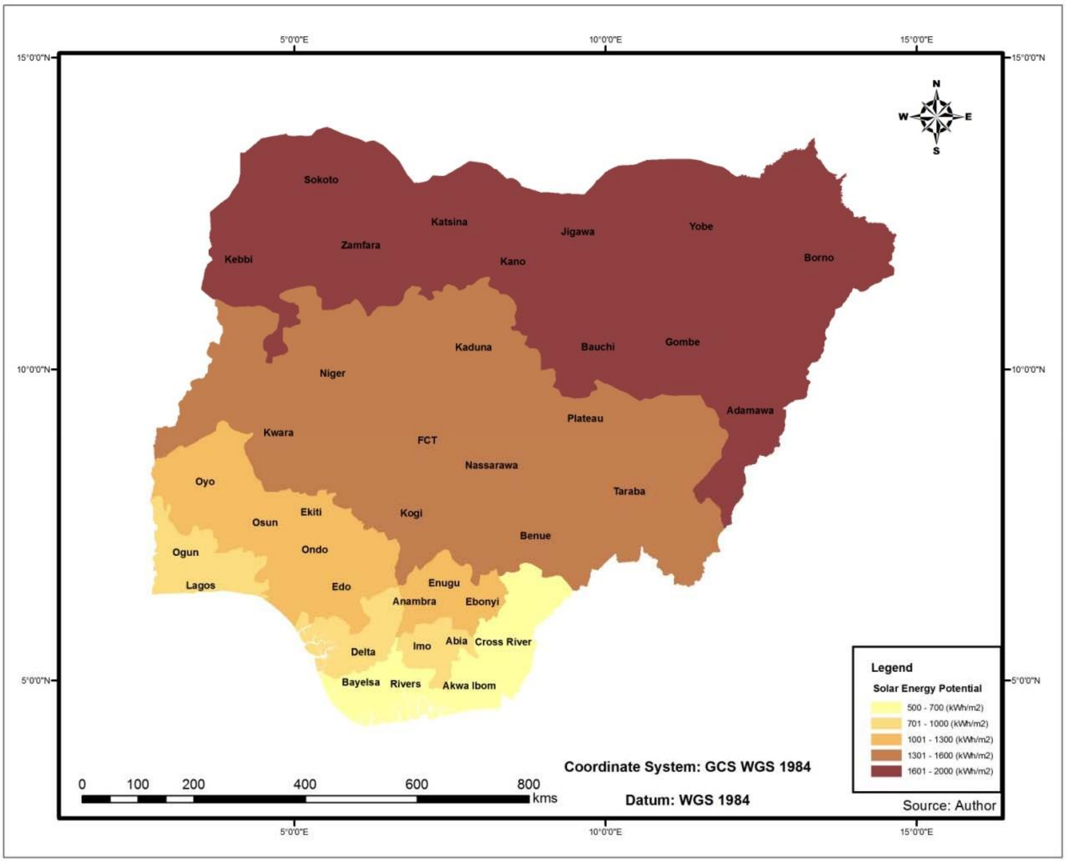

Figure 2. Solar Irradiation Map

2.4. *Wind Power*

Wind energy is presently used by some countries around the world as a renewable energy source for electric power generation. Wind power is verily available depending on the location and/or the season of the year. Wind technologies convert the energy of moving air masses at the earth's surface to electric power with the help of a wind turbine generator. There have been various studies worldwide on the prospects of local wind sites for electrical power generation, and Nigeria is not an exception. In a way to ascertain this assertion, Ogbonnaya *et al* in [21] carried out a study to see the possibilities of utilizing wind as an energy source in Nigeria using a 4 year of wind data from seven cities (Enugu, Jos, Ikeja, Abuja, Warri, Sokoto and Calabar). And it was reported that Sokoto is capable of a power potential as high as 97 MWh /year. In [20], it was reported that due to the varying topography and roughness of the nation, large differences in wind distribution within the same locality exist. According to the report using a 40 year (1968 − 2007) available average wind data from 44 wind stations across the Nigerian states obtained from NIMET shows that the wind regime is found to lie majorly between poor to moderate regimes, with the southern states having their mean wind profile at 10 m height in the range between 3.0 − 3.5 m/s, depending on the states, and Northern states capable with mean wind speeds of between 4.0 − 7.5 m/s [22]. Furthermore, it was also reported that wind speeds are generally weak in the south except for the coastal regions and offshore which have the potential for harvesting strong wind energy throughout the year but strongest in the hilly regions of the North, while the mountainous terrains of the middle belt and northern fringes demonstrated a high potential for a great wind energy harvest. Studies have shown that the highlands of Jos and some identified locations in the north-western part of Nigeria have the best potential sites for wind power and can be linked to the national electrical grid unlike the southern states with marginal wind that is only suitable for standalone electrical and mechanical applications like battery charging, street lighting and water pumping using small scale wind turbines [23,24]. In addition, reports state that the southern region of Nigeria, has its highest potential for wind energy harvest between the months of February and July (wet season), while in the northern region, the windier seasons vary with location [25]. The figure 3 shows the Isovents (m/s) across Nigeria based on measurements from NIMET's 44 stations at 10 m height over a period of 40 years (1968 - 2007).

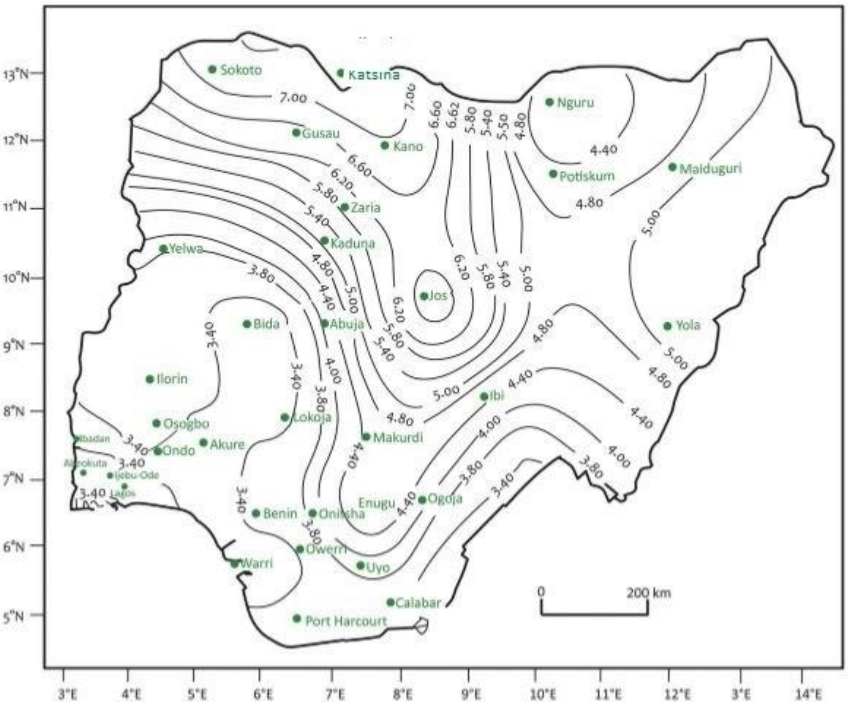

Figure 3. Isovents (m/s) across Nigeria [8,23]

2.5. *Biomass*

Biomass energy is simply the type of energy derived from organic materials that can be utilized for power generation. Biomass can be used directly through direct combustion or processed into another form such as biofuel (methane, ethanol etc.). The combustion of biomass releases carbon emissions but has been classified as a renewable energy source according to the United Nations legal framework, because plants can always be regrown through reforestation, and municipal solid waste is continuously generated provided human inhabitants and other anthropogenic activities are present. In most cases, biomass incineration technologies are constructed with one form of emission control system to reduce greenhouse gas (GHGs) emissions to the stipulated standards [1].

2.6. Municipal Solid Waste (MSW) as an Energy Resource

Municipal Solid Waste (MSW) is one of the major environmental problems facing mankind in the world today. However, efforts are being made globally to control the disposal, reduce the existing backlog in the environment landfills, transform and reuse it for human sustainable development. Recent estimates show that the waste sector contributes about one-fifth of global anthropogenic methane emissions [26] of which methane is a greenhouse gas that is 23 times more harmful for climate change than the same volume of CO_2 [27]. The exponential population growth in Nigerian urban cities is simultaneous to the increasing quantity of MSW generated which is of great concern with limited technological solution. The World Bank in [28] reported that Nigeria as a developing nation with a total urban population exceeding 70 million has its per capita generation of MSW as 0.56 kg/capita/day and estimated projection is expected to be at 0.8 kg/ capita/day by 2025. MSW as a resource for electrical power generation can be achieved by thermo-chemical conversion technologies (incineration/combustion, gasification, Refuse Derived Fuel (RDF)) and Biochemical conversion technologies (landfill gas, anaerobic digestion). Waste-to-Energy technologies are able to convert the energy content of different types of waste into various forms of valuable energy, hence electric power is produced and distributed through local and national grid systems [29]. The choice of technology is dependent on the economic viability and technical know-how due to some major criteria which include: Lower operational cost; Net operational cost; Complexity in technology and higher efficiency. According to [30], thermo-chemical conversion is preferably used due to its ability to ensure that the contribution of both biodegradable and non-biodegradable components of the waste are used for the energy output. However, the incineration with energy recovery is a good option for Nigeria to rapidly reduce the large volume of MSW in the environs, and simultaneously solve the current electric power crisis. Also, landfill gas recovery for power generation is an alternative because of the scarcity of land resources and it is considered a long-term plan for power generation and a contingency plan. The figure 4 and 5 below show the settlement and population maps of Nigeria as an indication of humans and their anthropogenic activities in Nigeria.

3. Discussions and Challenges

The sporadic power supply in Nigeria is because of over-dependence on hydro-electric power and thermal power from gas fired plants. The Nigerian renewable energy potentials remain untapped towards improving the existing power supply crisis in the nation. Nevertheless, the demand for electric power supply has grown exponentially compared to present power supply of about 4000 MW from the national grid. Several efforts were made to improve the situation in the Nigerian power sector by the privatization of the sector which has low impact so far. However, the major challenges inhibiting the growth of renewable energy in Nigeria are as follows:

- Lack of firm policies, regulatory framework and its implementation for RE resources and technologies has thwarted the growth, therefore investors (foreign and local) are not assured of their investment returns. Also, poor economic incentives and multiple taxation systems (federal, state and local government taxes) limit investors from establishing business in Nigeria.
- Lack of political will and commitment by the federal government towards policy framework implementation. In 2005, the Nigerian government came up with a Renewable Energy Master Plan (REMP) which was targeted to increase energy generation capacity from 5000 MW to 16000 MW by 2015. However, the government has shown no commitment towards achieving these goals.
- Absence of proper orientation programs for energy saving and sustainability: seeing that most of the end users in Nigeria use high energy consuming light fittings for illuminating their homes thus depriving other grid users of constant supply of electricity. For instance, some houses use 100W bulbs as their security light and 60 W bulbs for the inside of their houses. However, 10 W_{LED} bulbs could do the same home lightening.

- Poor maintenance, Affordability, and Sabotage: The deterioration of existing hydropower facilities and solar power pilot projects has led to low electric power productivity because of poor maintenance. Also, the high cost of RE technologies such as wind power, and solar panels is discouraging for local authorities and individuals. The concern on sabotage and loss of huge financial investment by the government has deterred the establishment of solar and wind farms for large scale power generation.
- Zero effort on energy recovery from MSW: the carbon component in MSW can be recovered in the form of electricity and heat for cooling otherwise if allowed to build up into heaps indiscriminately in the environment, the risk of decomposition will enhance the production of greenhouse gases like methane and carbon dioxide which contribute to global warming.
- Lack of funding for Research and Development (R&D) of RE technologies in the research institutes and tertiary institutions.

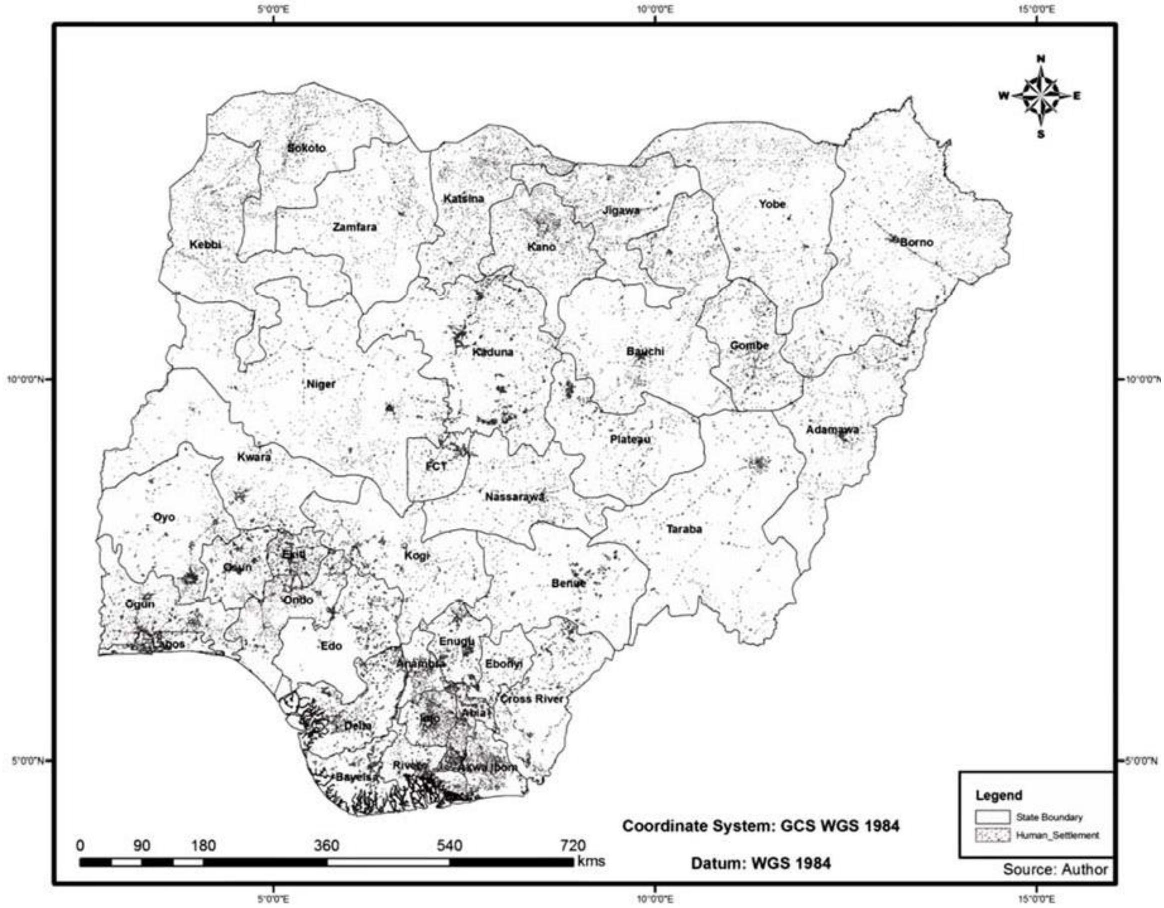

Figure 4. Settlement Map

4. Conclusions

In conclusion, it is evident that Nigeria as a nation is blessed with abundant renewable energy resources to tackle its erratic electrical power supply but very little has been done. The renewable energy resource such as hydro power, solar, wind, and biomass with respect to MSW due to urbanization are displayed in maps in various parts of the country (See figures 1, 2, 3, 4 and 5) for better visualization and understanding. The solar irradiation intensity is abundant in the northern parts of Nigeria compared to the south, and with solar energy, studies stated that there is a possibility of generating about 1850 X 10^3 GWh/year of solar electricity which is above 100 times the current grid electricity consumption level in the country.

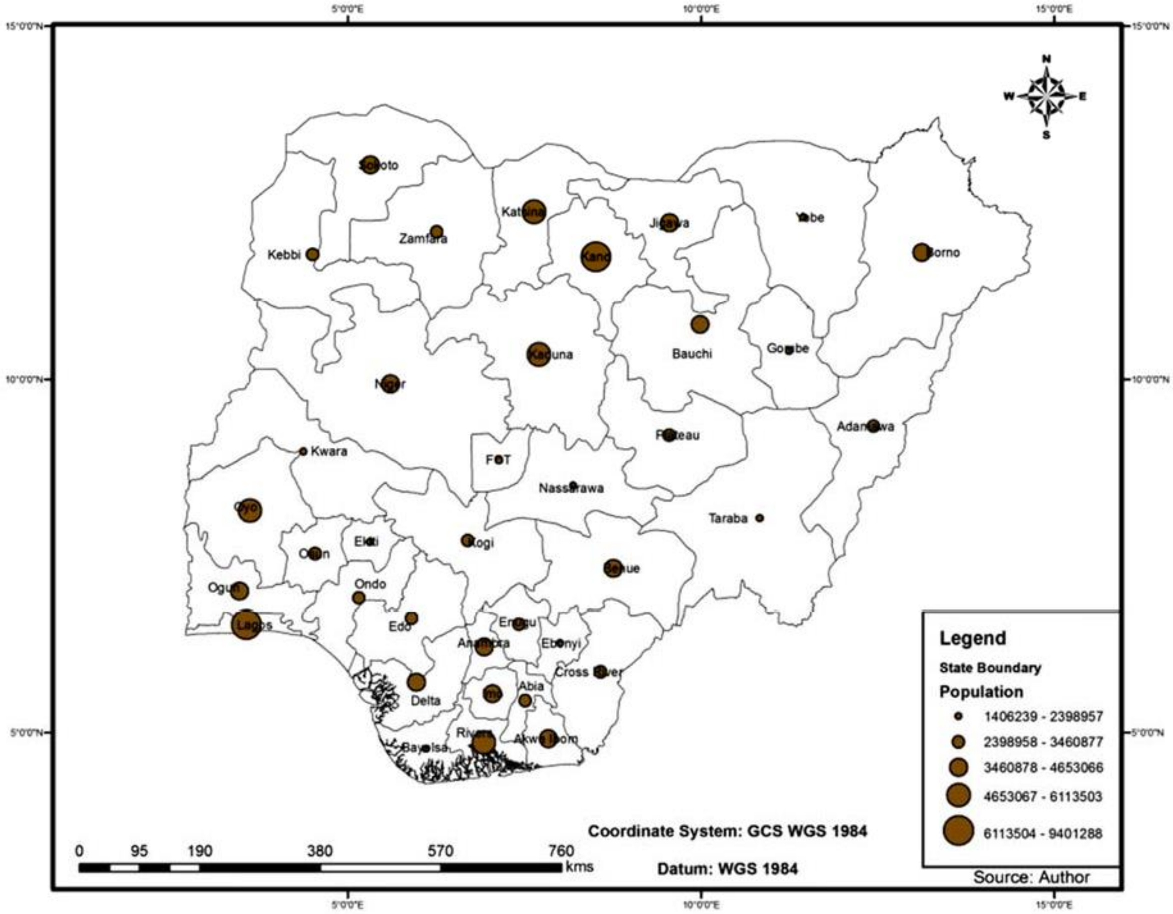

Figure 5. Population Map

However, hydro is the most common RE resource used for power generation in Nigeria that is not fully harnessed because of its huge capital and maintenance cost. The 3 major hydro power stations (Kanji, Jebba and Shiroro) generate in combination less than its installed capacity and the Small Hydro Power (SHP) potentials is still not fully exploited. Again, the tidal power can be explored using the coastal belt of Nigeria, but the cost implications and other constraints need to be properly evaluated. Studies have shown that the Southern and Northern states in Nigeria have huge wind power potentials but results show that wind power generation can be sustainable in some parts of the Northern states (Sokoto, Jos, Katsina, Kano and Zamfara), and the coastline states from Lagos state to Akwa Ibom state. It was also deduced that seasonal variations in Nigeria influence the power generation output for instance the water levels in the hydro-power dams, and also the intensity of wind (depending on the location) and solar irradiation. MSW is generated by inhabitants everyday throughout the year in any society because of the human activities in such environment. The present mean per capita generation of MSW in Nigeria is 0.56 kg/person/day, having about 70 million residents in the urban areas shows that the power generation potential from Waste–to-Energy can be feasible and sustainable provided the right technology is used.

5. Recommendation

Firstly, it is recommended that the sensitization initiative on energy conservation to the people will promote a huge reduction in energy cost so that other grid users can benefit from constant power supply. Also, the Nigerian government should invest not only its financial capacity, but its political will and implementation plan to ensure that renewable energy resources are fully harnessed. Decentralized energy system should be encouraged in order to ensure that electrical power generated from RE sources in rural communities conserves the energy lost during transmission, reduces the initial cost by the size and number of power lines to be constructed so that the power generated on-site is utilized within a defined locality. The need to integrate Independent Power Project of Nigeria is significant in order to encourage individuals, industries and other stakeholders to own their standalone renewable energy systems which enables them to generate, utilize and sell the excess energy to the national grid. The Energy Commission of Nigeria (ECN) should be more proactive in its jurisdiction to ensure that all areas of RE are fully explored through research and development and trainings for its expertise on the latest RE trend in the globe. And lastly, local content technology should be encouraged through research and development (R&D) and also there should be a synergy among the research institutes, tertiary institutions, and private investors with the aim of promoting exports and socio-economic development in Nigeria.

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5.3 Waste to energy as a complementary energy source in Abuja, Nigeria

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ABSTRACT: The Nigerian national power output is less than 4000 MW from fluctuating sources such as hydro power (seasonal) and gas-fired plants (prone to sabotage). Municipal Solid Waste (MSW) is a burden to the environment in terms of its health risk and its management but also an underrated energy source in Nigeria. Hence, this study aims at investigating the MSW in Abuja as a supplementary resource for power generation. The study focused on Waste to Energy by incineration as an instant solution for both MSW reduction as well as power generation. Also, the study employs proximate and ultimate analysis to evaluate the Lower calorific Values (LHV) for Porto & Abuja to determine the Power Generation Potential (P_{gp}). Furthermore, a comparison approach is considered to establish a relationship between $P_{gp\ (Porto)}$ & $P_{gp\ (Abuja)}$ from MSW to estimate, project and predict energy output from WTE incineration plant in Abuja, Nigeria.

1 INTRODUCTION

The growing concern on an eco-friendly environment to sustain the globe for the generations to come is of significant interest. Current paces of urbanization, consumerist societies and waste generation have challenged the global sustainability in many ways (Visvanathan *et al*., 2007). Most cities in Africa are confronted with the intricacy of Municipal Solid Waste (MSW) management, its collection and disposal. The primary sources of MSW are from residences, institutions, commercial establishments, inert waste from industries and hospitals, and agricultural activities. MSW is obviously becoming a major challenge in major cities of developing nations due to rapid urbanization and increasing population growth (Aderoju *et al*., 2015). The World Bank (2012) reported that the estimate of the global MSW generated is about 1.3 billion tonnes yearly and it increases by 1% yearly. Recovery is one aspect of sustainable waste management that is based on the well-known hierarchy of "prevention" "reuse", "recycling", "recovery" and "disposal". Waste-to-energy (WTE) refers to the recovery of heat and power from waste, and non-recyclable waste (Ryu and Shin, 2013). The increasing clamour for energy and satisfying it with a combination of conventional and renewable resources is a huge challenge (Jain *et al.*, 2014). Non-conventional energy exploitation through the useful harnessing of biomass energy locked up in the urban solid waste stream into grid energy seems to be a more probable option that has gained both political and public discussions on alternative energy sources (Akuffo, 1998). The WTE industry has proven itself to be an environmentally friendly solution to the disposal of MSW and the production of energy (Kumar *et al.*, 2010). The decomposition of organic waste in dumpsites continuously emits greenhouse gases, which contribute enormously to the depletion of the ozone layer and global warming. The proper reuse of MSW improves sanitation in urban centres, decreases emissions of greenhouse gases due to its decomposition and in turn helps to reduce the consumption of fossil fuels (Possoli *et al.,* 2013). The sporadic supply of electricity has brought a damaging setback to the Nigerian economy such that a complete-halt of operation by some major companies making them flee the country to nearby countries where constant electric power supply is assured. With hap-hazard dumpsites defacing the Nigerian cities, little or no effort has been made to utilize MSW as a resource towards a waste-to-energy (WTE) solution. The over-dependence on both hydro (which is seasonal), and natural gas (which is prone to sabotage) for power generation has led to the production of less than 4000 MW for a population of over 183 million people. In general, the concept of WTE in Nigeria is a welcoming development and a great positivity to the economy by harnessing MSW stream as a resource for electrical power generation. WTE technology significantly reduces the menace of excessive and continuous MSW generated in our major cities, promotes a sustainable aesthetic environment, electrical power generation and distribution, job creation, revenue generation and transition to a clean energy economy in Nigeria. On this note, the study aims to utilize MSW stream as a supplementary solution for power generation and distribution Nigeria. The study limits its investigation of the two most populated local government area in Abuja which are AMAC (Abuja Municipal Area Council) and Bwari LGA such that their MSW can be utilized for power generation.

2 AN OVERVIEW OF WTE (INCINERATION) CONCEPTS IN ENERGY RECOVERY

The continued concerns over energy prices, increasing population and climate change issues has led the drive towards a need for alternative and new energy sources (Amoo and Fagbenle, 2013). However, renewable energy resource remains that which is boundless, and it is replenished naturally such as hydro, wind, solar, and biomass. MSW has its major constituent as organic waste and others like plastics which are products of fossil fuel are continuously generated by humans in the environment. Therefore, WTE is recognized as a promising alternative for waste management to overcome the waste generation problem and as a potential renewable energy source (S.T Tan *et al*., 2015). WTE technologies are able to convert the energy content of different types of waste in various forms of valuable energy, hence electric power is produced and distributed through local and national grid systems (WEC, 2013). About 130 million tons of MSW are worldwide burned annually in 600 plants based on WTE that generate electricity, steam for heating purpose and recovered metals for recycling (Themelis, 2003). Waste combustion according to Voelker (2000) provides integrated solutions to the problems of modern era "by recovering otherwise lost energy, thereby reducing our use of precious natural resources, cutting down our emissions of greenhouse gases, saving valuable land that would otherwise be destined to become landfill and recovering land once scarified to product of consumerism. Kagkelidou in 2005 estimated that the net electrical energy provided to utilities for each ton of solid waste corresponds to saving 170 liters of fuel oil. Recent technological advances and tighter pollution regulations ensure that modern WTE facilities are cleaner than almost all major manufacturing industries (Hazardous Waste Resource Center, 2000). According to Suberu *et al*., (2012), thermo-chemical conversion is preferably used due to its ability to ensure that the contribution of both biodegradable and non-biodegradable components of the waste are used for the energy output. Studies have shown that, the lower operational cost, higher energy output and less complexity in technology, and its instant operation makes WTE by incineration the most suitable. MSW incineration to energy appears to be most suitable for Nigeria due to the massive reduction of MSW in the environment and also as an immediate additional solution to the current electric power crisis.

3 METHODOLOGY

This study is based on utilizing MSW in Abuja Municipal Area Council (AMAC) and Bwari area council for electricity. This study intends to demonstrate a possible concept to evaluate, predict and project the power generation potential of the MSW in Abuja through a comparative approach using two cities (Porto and Abuja). Also, estimating of the calorific values of the MSW samples and the energy recovery potential for (Porto & Abuja) is essential using this approach.

3.1 Study area

Abuja is the capital city of Nigeria, located in the center of Nigeria in the Federal Capital Territory (FCT) within latitude 7º 25' N and 9° 20' N of the equator and longitude 5° 45' E and 7° 39’ E of the meridian. The Federal Capital Territory has a land area of 7,753.85 km^2 square kilometers. It has a population of about 2,238,800 persons (NPC, 2011). It experiences majorly wet and dry seasons. Abuja experiences an average daily minimum and maximum temperature of 20.5ºC and 30.8ºC respectively. It has a mean rainfall and humidity of about 119.2 mm and 58.4% respectively with the highest rainfall in August and lowest between November and March respectively.

3.2 Basic characterization and sample preparation of MSW in AMAC and Bwari area council

The physical characteristics to be measured in waste are basically the classification of the waste stream components, quantity in terms of mass or volume, and the degree of wetness. In the study area, the four major dumpsites identified and visited were Kubwa, Dutse, Gosa and Karshi dumpsites. Furthermore, 10 kg of freshly mixed MSW samples were collected at each dumpsite for characterization 3 times a week. The mixing, manual sorting and weighing was done to determine the MSW composition. The physical analysis was based on weight ratio of different components in the MSW stream. The percentage of samples composition was categorized into 8 different components which are: food waste/organic; textile; glass/Ceramics; metal; paper; plastics; rubber: and other waste. For power generation from MSW, incombustible components like metal, glass, ceramic wastes are separated for recycling.

3.3 Proximate analysis and ultimate analysis

In General, moisture content affects the self-sustained combustibility and the calorific value of the waste stream (Komislis *et al*., 2014). According to Dong *et al.*, in 2002, proximate analysis determines the moisture, volatile matter, fixed carbon and ash content of the waste sample. With the assumption that calorific value is proportional to the carbon content and hydrogen in the sample, then Higher Heat Value (HHV) is assumed to be a function of the quantity of fixed carbon in percentage present in which volatile matter percentage has its main components as carbon and hydrogen (Gunnamatta, 2016). The combustible components in the waste sample are weighed and heated separately in the oven for 1 hour to determine the moisture content and dry mass of each component in the MSW sample. An additional loss of weight on ignition at 950°C for 30 min is used to determine the % volatile matter (dry basis) and % ash content (dry basis).

The ultimate analysis of waste analyzes the percent of carbon, hydrogen, oxygen, nitrogen, sulphur and ash present in the MSW sample. Provided the dry mass of each component in the MSW sample is determined, the elemental contents like carbon, hydrogen, oxygen, nitro- gen, sulphur and the ash content for waste sample can be determined using the standard table of ultimate analysis of combustible waste in Tchobanoglaus *et al*., (1977); Wess *et al*., (2004); Othman (2008) and it is expressed as;

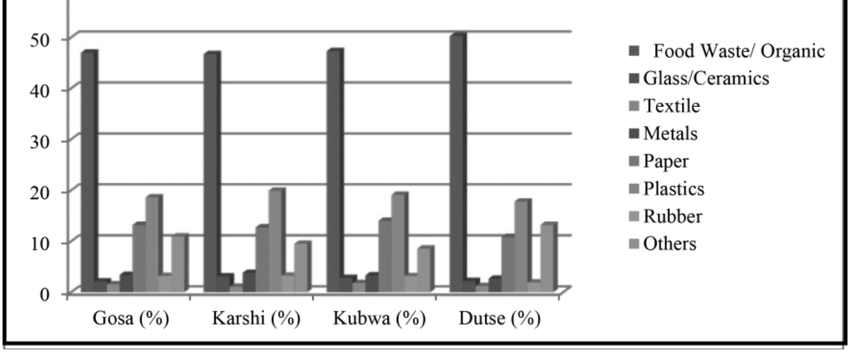

Figure 1. Dumpsites composition in AMAC and Bwari area council. Source: Author.

$$\text{Elemental Content (kg)} = (\text{Dry mass}*\text{Standard element (C/H/O/N/S) value})/100 \quad (1)$$

Where:

The Standard element (C/H/O/N/S) value in the MSW components is obtained from the standard table of ultimate analysis of combustible waste. This is estimated for total components present in the waste sample and cumulated to arrive at a (C, H, O, N, S) value of the sample which is substituted into the Dulong equation. The HHV value can be determined using the modified Dulong equation which considers nitrogen and it is expressed as:

$$\text{HHV (kJ/kg)} = 337\text{C} + 1419(\text{H}_2 - 0.125\text{O}_2) + 93\text{S} + 23\ \text{N} \quad (2)$$

Where: C = Carbon (%), H = Hydrogen (%), O = Oxygen (%), S = Sulphur (%), N = Nitrogen (%)

3.4 Calorific value estimation for MSW energy potential

Calorific measurement can be described as an assessment of the energy output and the degree of combustion of the waste stream that is used in evaluating the economic viability of a WTE project. The calorific value is classified into the Higher Heat Value (HHV) and Lower Heat Value (LHV). HHV is described as the quantity of heat generated by a complete combustion of a unit mass of sample in air or oxygen, such that the product of combustion cooled down to the room temperature and still remains in liquid form (Franjo *et al.*, 1992). However, LHV is the net heat produced when a unit mass of the sample is completely burnt in air or oxygen, such that the product of combustion can escape as steam. LHV of the MSW sample is calculated in Prasada Rao *et al*., (2010) as:

$$\text{LHV} = \text{HHV} - 9\ (\text{H\%}) * \text{LHS} \quad (3)$$

where; LHV = Lower Heat Value of each component (kcal/kg), HHV = Higher Calorific Value of each component (kcal/kg), LHS = Latent Heat of Steam which is 587 (kcal/kg), H% = hydrogen percentage of the sample.

3.5 Energy recovery potential and power generation potential

The possible amount of energy recovered from MSW based on different conversion methods is a function of its calorific value and organic content (Tsunatu *et al*., 2015). Thus, thermo-chemical conversion utilizes all its organic matter, biodegradable as well as non-biodegradable for energy output. The Energy Recovery Potential for the thermo-chemical conversion of MSW is expressed as:

$$E_{rp}\,(\text{kWh}) = \text{LHV} * \text{Wt} * (1000/860) * \eta \quad (4)$$

where; E_{rp} (kWh) = energy recovery potential of MSW sample in kWh, LHV = Lower Heat Value (kcal/kg), Wt = Weight of waste (tons), η = Conversion Efficiency which ranges between 22–28% (IEA, 2007).

Furthermore, the Power Generation Potential (P_{gp}) is the amount of energy that can possibly be generated daily. It is expressed as:

$$P_{gp}\,(\text{kW}) = E_{rp}/24 \quad (5)$$

3.6 Comparative power generation potential (Porto and Abuja)

The comparison has the tendency of establishing a relationship between the $P_{gp\ (Porto)}$ and $P_{gp\ (Abuja)}$. This approach considers the LHV of the MSW sample and the MSW (Wt) to obtain the $E_{rp\ (Porto)}$ & $E_{rp\ (Abuja)}$ respectively. Furthermore, the $P_{gp\ (Porto)}$ & $P_{gp\ (Abuja)}$ having known the E_{rp} of both locations is expressed as:

$$P_{gp\ (Abuja)} = E_{rp\ (Abuja)} / 24 \tag{6}$$

$$P_{gp\ (Porto)} = E_{rp\ (Porto)} / 24 \tag{7}$$

By substituting Eq. (4) into Eq. (6) & Eq. (7):

$$\text{Hence: } P_{gp\ (Abuja)} = LHV_{\ (Abuja)} * Wt * 0.04845 * \eta \tag{8}$$

$$P_{gp\ (Porto)} = LHV_{\ (Porto)} * Wt * 0.04845 * \eta \tag{9}$$

The relationship between the $P_{gp\ (Porto)}$ & $P_{gp\ (Abuja)}$ can be established by evaluating the $P_{gp\ (Porto)}$ & $P_{gp\ (Abuja)}$ using the Wt repeatedly at varying and regular intervals in Eq. (8) & Eq. (9). Also, the evaluated results are plotted against the Wt such that a possible mathematical correlation is expected between $P_{gp\ (Porto)}$ & $P_{gp\ (Abuja)}$ respectively.

4 DISCUSSION

Generally, the P_{gp} using MSW in a WTE plant is dependent on the LHV and the quantity of MSW (tons). Also, the LHV basically requires that the condition of the waste stream in terms of chemical and physical characteristics is satisfactory before it is used as a resource for power generation. Using proximate and ultimate analysis, the HHV is obtained with the aim to evaluate the LHV. Recall that there are no similarities in terms of per capital daily genera- tion, LHV, and the population of both locations (Porto & Abuja). However, for comparison approach the same weight of MSW is used at varying interval like (100 tons, 200 tons, ….. 1000 tons) alongside the $LHV_{\ (Porto)}$ & $LHV_{\ (Abuja)}$ in Eq. (8) & Eq. (9) to arrive at P_{gp} for both locations respectively. The $P_{gp\ (Porto)}$ & $P_{gp\ (Abuja)}$ will be plotted against the MSW weights (Wt) to establish a relationship if any. In case there is a relationship, it can be used to estimate and make projections for the possible amount of power in kW for every ton of MSW in Wt.

5 CONCLUSION

The practice of generating energy from waste for domestic and other uses has been demonstrated in commercial quantity by most developed countries in Europe, America and Asia. Incineration with energy recovery indeed has been proven environmentally sound due to the advancement in technology over the years. The problem of exponential generation of MSW in Nigeria has become an overburden on both the environment and authorities. The study employed a comparative approach for Power Generation Potential (P_{gp}) of Porto (Portugal) and Abuja (Nigeria) to give an idea on how to arrive at a standard relation in the form of a mathematical expression for the prediction and projection of the possible amount of electric energy (kW) from a certain quantity of MSW (tons) for Nigeria, provided all the necessary criteria are fulfilled. The merit of this study tends to reduce the volume of MSW streams in major Nigerian cities and simultaneously serve a resource for electric power generation. This study provides a new scope for government and other stakeholders to invest towards providing basic sustainable infrastructure for better quality of life and concurrently create an eco-friendly environment for the generations to come.

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A Comparative Analysis of City-Based MSW for Power Generation.

Abstract

The erratic electricity supply in Nigeria has triggered some drawbacks in the growth of the economy which has led to some major companies relocating to neighboring countries where constant electric power is assured. Again, the rapid population growth of Abuja, Nigeria as a result of migration and immigration of people with different culture and nationality has led to an excessive Municipal Solid Waste (MSW) generation with little waste management strategy. However, safeguarding the social welfare of the citizens is paramount to the government. On this note, the study aims to utilize MSW stream as a supplementary solution for power generation and distribution in Nigeria. Furthermore, the study used the proximity, and ultimate analyses to estimate the calorific values (Higher Heat Value (HHV) and the Lower Heat Value (LHV)) of the MSW components for Abuja, Nigeria, and Porto, Portugal; also, the study estimates and compares the cities' power generation potential (Qgp) from the MSW. The results showed that the calorific values estimated from the MSW generated in Porto and Abuja are HHV (3136.05 kcal/kg and 3515.81 kcal/kg), and LHV (3117.38 kcal/kg and 3495 kcal/kg) respectively. The later includes results from the estimated Qgp (Porto) and Qgp (Abuja) using equivalent weights of 100 tons intervals from 100 tons to 2000 tons showed that the ratio between the Qgp of Porto to Abuja is 1: 0.89. Also, it depicts that the ratio of the population generating these equivalent weights (Wt) of MSW at per person daily generation for Porto and Abuja is 1: 1.71.

Key words: Municipal Solid Waste, Dumpsite, Calorific Values, Proximate Analysis, Ultimate Analysis, Waste to Energy, Power Generation Potential.

1. Introduction

The challenges of Municipal Solid Waste (MSW) is becoming a global menace that requires urgent attention. A study by World Bank (2012a) estimated that the global MSW generation is approximately 1.3 billion tons per year or an average of 1.2 kg/person daily. Several studies have described the conventional practice of MSW management in many developing nations like Nigeria as follows: collection, transportation, open land disposal, ocean dumping, open-air burning, recycling (uncommon) among others. Ojha et al. (2012) reported that most common disposal methods in the study countries indicate the share of open dumping to be 90% in India, 85% in Sri

Lanka, 65% in Thailand and 50% in China. Developing countries are not able to cope with the MSW generation growth, and open landfills remain the dominant method of disposal (Ouda et al. 2013). In a report by Agll et al. (2014), it was stated that the inhabitants of any community will always generate MSW irrespective of the size, level of development, and financial status of the people. Again, the World Bank (2012b) reported that Nigeria as a developing nation, has a total urban population exceeding 70 million with its per capita generation of MSW at 0.56kg/capita/day and the estimated projection is expected to be at 0.8 kg/ capita/day by 2025. Ogwueleka in 2009 also reported that the density of solid waste in Nigeria ranges from 280-370 kg/m^3 with waste generation rate of 25 million tons annually and at a daily rate of 0.44-0.66 kg/capital/day. Nwachukwu (2010) also reported that in the city of Onitsha, more than 730,412 people generates 370706 tons/annum, and in Lagos, the commercial center of Nigeria, 21 million people produces more than 10,000 tons of MSW daily at the rate of 0.5kg/capita/day. Babayemi and Dauda (2009) described the solid waste management in Nigeria as being challenged with ineffective collection technique, inadequate coverage of the collection routine and unlawful dumping of solid waste. Also, Hauwa (2003) and Momodu et al. (2011) discerned that improperly sited open dumps defaced cities, thus endangering the public health by encouraging the spread of offensive odors, whereby sites have become fertile ground for breeding flies and other vectors, pollution of water sources and environmental degradation at large. The decomposition of organic waste in open dumpsites continuously emits greenhouse gases, which contribute enormously to the depletion of the ozone layer and global warming (Aderoju and Dias, 2018). In a report by the UNU-WIDER (2010), it was established that over one billion people living in low income communities and slums lack appropriate waste management services. It further stated that methane is generated as a result of decomposition of the organic fraction of MSW in indiscriminate dumps could cause explosions. In addition, it is possible to harness methane (biogas) from landfill to generate energy. However, studies have shown that harnessing biogas from a landfill requires; land space which is a scarce commodity as a result of rapid urbanization, time (some years) for biogas to build up, and extra cost for pipe network for the removal of leachate and channeling of methane to a storage chamber. More so, people are becoming more conscious of the environmental impacts of increasing landfills (Themelis, 2006). Consequently, rapid urbanization and lack of space new landfills in big cities are switching to incineration (Sivapalan et al. 2003). Hence, adequate management of MSW in our environs is required to improve the sanitation of the environment, which will probably decrease the emission of greenhouse gases. Several studies have shown that the best management practice requires that MSW must have undergone processes such as sorting, material and energy recovery, treatment before final disposal (Nnaji, 2015). Moreover, the physical and chemical characteristics of MSW indicate that its composition is directly influenced by the local aspects such as food habits, culture, socio-economic, seasonal, and climatic conditions (Bhoyar et al. 1996). In the search for a possible strategy to tackle this menace, Voelker (2000), reported that waste combustion provides an integrated solution to the problems of modern era “by recovering otherwise lost energy, thereby reducing our use of precious natural resources, cutting down our emissions of greenhouse gases, saving valuable land that would otherwise be destined to become landfill, and recovering land once scarified to product of consumerism. In a study by Aderoju et al. (2017), it was reported that MSW as a resource for electrical power generation can be achieved by thermo-chemical conversion technologies (incineration/combustion, gasification, Refuse Derived Fuel (RDF)) and Biochemical conversion technologies (landfill gas, anaerobic digestion). Suberu et al. (2012) concluded that thermo-chemical conversion is preferably the best option of the technologies due to its ability to utilize both biodegradable and non-biodegradable components of the waste for energy output. Waste-to-Energy (WTE) technologies offer one option for relieving the pressure on landfill sites, thereby alleviating the strain on the current infrastructure, and at the same time recovering the energy value of the waste and providing a renewable and sustainable source of clean energy (Themelis, 2003). Therefore, the incineration with energy recovery is a good option for waste management as it helps to overcome the waste generation problem in the environs, and simultaneously solves electric power crisis through its renewable energy potential (Tan et al. 2015; Aderoju et al. 2017).

In recent times, several researchers have investigated the Higher Heat Value (HHV) and Lower Heat Value (LHV) of MSW to estimate its energy potential for power generation. A study by Sivapalan et al. (2003) evaluated the amount of energy that would be recovered from incinerated MSW in Kuala Lumpur, Malaysia. The calorific value was estimated in accordance to the American Society for Testing and Materials (ASTM E 711-87). The results showed that food waste, paper and plastic make up to 80% of the MSW by weight; and its calorific values range between 1500 kcal/kg and 2600 kcal/kg. In addition, the amount of energy that could be recovered by incineration was evaluated, it was deduced that incineration does give high returns on energy while staying low on environmental effect and on the energy consumed to treat the MSW. Thus, it was concluded that the energy potential from an incinerator plant based on 1500 tons of MSW daily with an average calorific value of 2200 kcal/kg was assessed to be at 639kW for every ton of MSW daily. In another study, Franjo et al. (1992) describes the process to calculate the calorific value of Spain’s MSW using a conventional bomb calorific method. The calorific values were measured by a static bomb calorimetry directly for mixed MSW, and for the individual component of MSW separately. Results showed that the LHV of the mixed MSW was 10235 kJ/kg while the average summation of each individual component of MSW measured separately was estimated as 10362 kJ/kg, which is as a result of heterogeneous nature of the mixed MSW compared to the sorted MSW. In addition, Menikpura et al, (2007) also determined the energy potential of the MSW in Kandy Municipality, Sri Lanka. The MSW was analyzed, weighed and later separated into combustibles and non-combustibles. A bomb calorimeter was used to conduct the energy values of different MSW types that are combustible. The results showed that the MSW produced considerable amount of energy at minimum and maximum calorific values on dry basis at 14000 kJ/kg and 45000 kJ/kg for plastics and wood respectively. These experimental results were validated in Sri Lanka with the Shafizadeh model after it was adjusted to be more suitable for the MSW. The results were compared with the estimated results from the Dulong model; likewise, with the estimated results from Shafizadeh, and the modified Shafizadef models. It was also deduced that the MSW obtainable in Kandy daily is 684 GJ, which amounts to 69.3 GWh.

Over the years, Nigeria has been facing two most important socioeconomic problems (MSW management and sporadic electric energy supply) that notably affect its people. MSW management has always been a challenge for most Nigerian cities' authorities as a result of the excessive waste generation, poor collection and disposal sites, and the issue of limited funds due to the high costs of operation and management. On the other hand, the erratic power supply in Nigeria has triggered some drawbacks in the growth of the economy which in turn has led to some major companies are relocating to neighboring countries where constant electric power is assured. The over-reliance on seasonal hydropower source and thermal gas plants whose gas pipeline is prone to vandalization have brought no improvement in the electricity supply in Nigeria. Consequently, the concept of WTE in Nigeria will be a welcoming development, and a great positivity to the economy by exploiting the MSW stream as a resource for electrical power generation. Studies have shown that the lower operational cost, higher energy output and less complexity in technology, and its instant operation makes incineration with energy recovery the most suitable.

Abuja, being the capital city of Nigeria has attracted a lot of migration and immigration of people with different culture. Several studies have confirmed that the rapid population growth of Abuja has exceeded the city's Master Plan. As a result, it has led to an excessive MSW generation with no proper waste management strategy but a single routine of collection and discard to dumpsites. Moreover, the low or no supply of electricity to households and commercial organizations has raised a lot of concern from the authorities and the inhabitants of the country at large. Thus, this study intends to exploit the menace of excess MSW as an advantage and possible solution to meet the electrical power demand of the populace. On this note, the study aims to utilize MSW stream as a supplementary solution for power generation and distribution in Nigeria. Furthermore, the study estimates the LHV of the MSW components in Abuja, Nigeria and Porto, Portugal; also, compares the power generation potential (Qgp) of Abuja and Porto. WTE technology is widely known to significantly reduce the menace of excessive and continuous MSW generated in our major cities. It is likely to promote a sustainable aesthetic environment, electrical power generation and distribution, job creation, revenue generation and transition to a clean energy economy in Nigeria.

2. Materials and Methods

This study is based on utilizing MSW in Abuja Municipal Area Council (AMAC) and Bwari Area Council for electricity. This study intends to demonstrate a possible concept to evaluate, predict and project the power generation potential of the MSW in Abuja through a comparative approach using two cities (Porto and Abuja). These two cities were used for the comparative analysis due to the similarities in temperature during the summer (Porto) and dry seasons (Abuja); intense rains with wind during rainy seasons; and high rate of immigration as a result of tourism and peaceful environs (Porto), the capital city of Nigeria (Abuja). Also, estimating of the calorific values of the MSW samples and the energy recovery potential for (Porto & Abuja) is essential using this approach.

2.1. Study Area

Abuja is the capital city of Nigeria, located at the center of Nigeria, in the Federal Capital Territory (FCT) within latitude 7° 25' N and 9° 20’ N and longitude 5° 45' E and 7° 39' E (see fig. 1). The Federal Capital Territory has a landmass of about 7,753.85 square kilometers. In addition, the population of Abuja is estimated to about 2,238,800 persons (NPC, 2012). Abuja lies within the Guinea savannah vegetation belt and experiences two seasons, namely dry and wet seasons. It experiences majorly wet and dry seasons. Abuja experiences an average daily minimum and maximum temperature of 20.5^{o}C and 30.8^{o}C respectively. It has a mean rainfall and humidity of about 119.2 mm and 58.4%, with the highest rainfall in August and lowest between November and March. Abuja has been dubbed as one of the fastest growing cities in Nigeria, and as a result, various activities contributed to the exponential increase in the quantity of MSW in the Abuja environs between 2001 – 2014 (see fig 2). Also, in 2014, the fig. 3 shows the monthly data collection of MSW (tons) in Abuja that ended up in designated dumpsites by the Abuja Environmental Protection Board (AEPB). The average per capita generation of MSW in Abuja was estimated to be at 0.76 kg/person daily (AEPB, 2015).

Also, the province of Porto is the second largest regional city of Portugal after Lisbon. located in the northern region of Portugal, within the latitudes 41º 29' N and 40º 59' N and longitudes 8º 47' W and 7º 51' W (see fig. 4). The city proper has a population of 237,591 and the metropolitan area of Porto, which extends beyond the administrative limits of the city, has a population of 1,817,172 persons (Instituto Nacional de Estatística, 2011) in an area of about 2,331.7 km^2 (CAOP, 2017). The average minimum and maximum temperatures of Porto are at 9ºC and 19ºC respectively during the winter and summer seasons. Also, the average annual rainfall and humidity is about 999.9 mm and 79% respectively (IPMA, 2018). The average per capita generation of MSW in Porto was estimated to be at 1.3 kg/person daily (Lipor, 2014). The companies in charge of the collection of Gaia waste is Suldouro while Lipor deals with collection of Porto MSW.

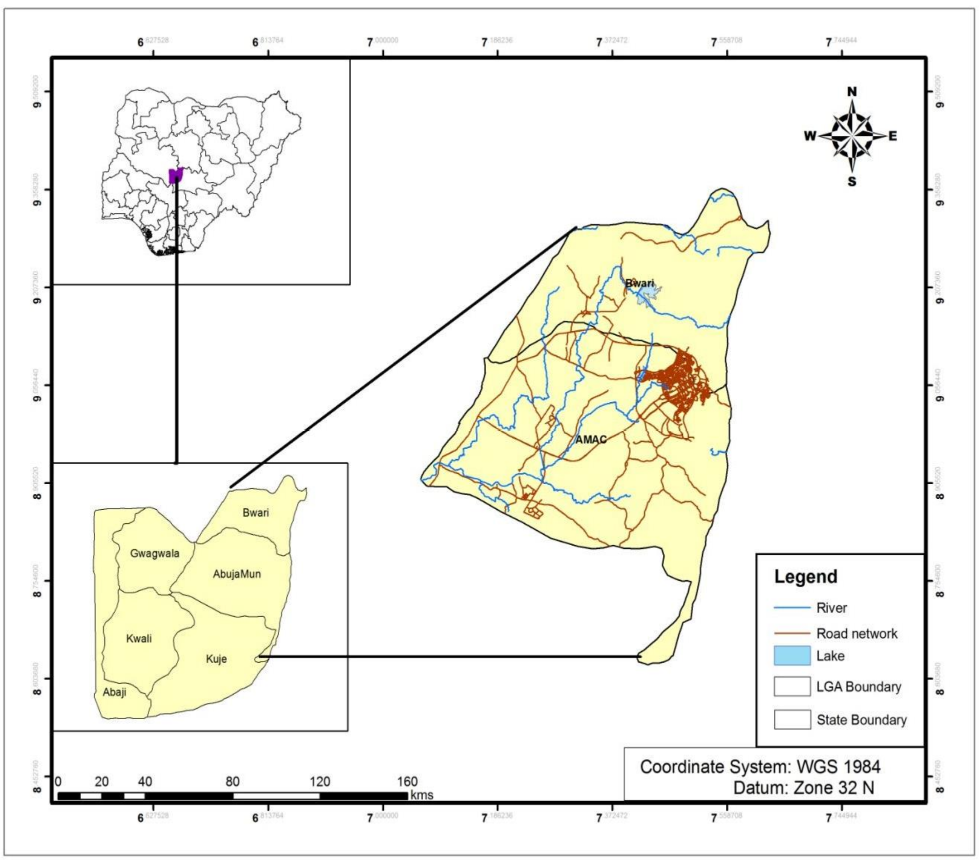

Fig. 1 Study Area Map (Abuja). *Source*: Aderoju et al. 2018

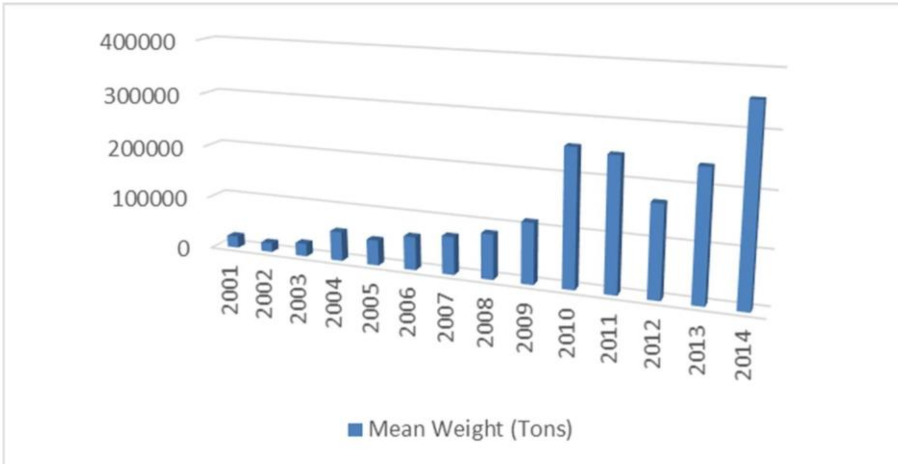

Fig. 2: Abuja MSW Collection Data *Source*: AEPB, 2015

Fig. 3: Abuja 2014 MSW Collection Data *Source*: AEPB, 2015

Fig. 4 Study Area Map (Porto).

2.2. Physical Analysis & Sample Preparation of MSW in Abuja & Porto.

The physical analysis is described as the basic classification of the waste stream components in terms of mass or volume, and the degree of wetness. In Abuja (AMAC and Bwari Area Council), four major dumpsites namely: Gosa; Karshi; Kubwa; and Dutse were identified and visited to carry out MSW characterization. The ASTM test method ASTM D5231-92, (2006) was adopted for the characterization of the MSW at the dumpsites in the study area. The analysis of the study commenced with the manual collection of 10 kg of freshly mixed MSW samples at each dumpsite for characterization 3 times a week for 4 weeks during the wet and dry seasons. The process of mixing, manual sorting and weighing of the collected MSW was done in-situ to determine the composition. The physical analysis which is the characterization of MSW into various components was based on weight ratio of different components in the MSW stream. The percentage of samples composition was categorized into 8 different components which are: food waste/organic; textile; glass/ceramics; metal; paper; plastics; rubber: and other waste materials. The components referred to as other waste includes tiny stones and grit, used batteries, and composite materials. The mean weight ratio for each of the dumpsites for both dry and wet seasons is shown in fig. 5.

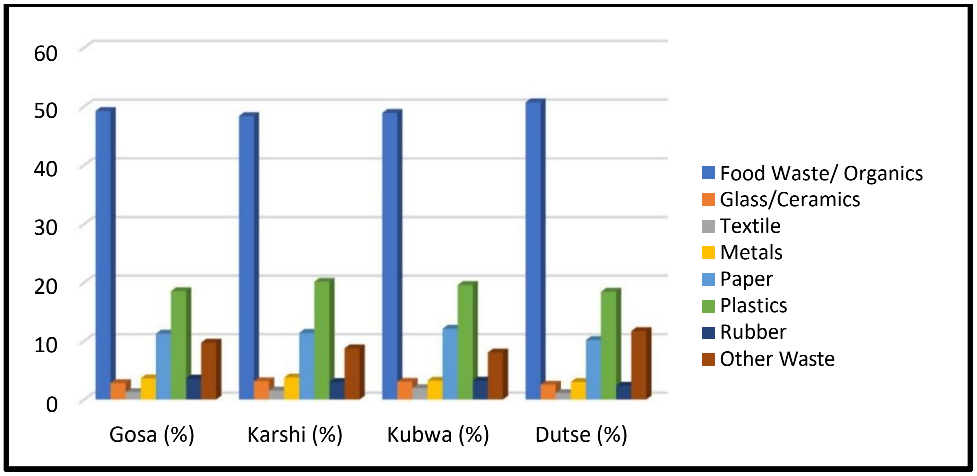

Fig. 5: Dumpsites Composition in Study Area *Source*: Aderoju and Dias (2018).

2.3. Proximate Analysis

Generally, moisture content affects the self- sustained combustibility and the calorific value of the waste stream (Komislis et al, 2014). According to Dong et al, 2002, proximate analysis determines the moisture, volatile matter, fixed carbon and ash content of the waste sample. With the assumption that calorific value is proportional to the carbon content and hydrogen in the sample, the Higher Heat Value (HHV) is assumed to be a function of the quantity of fixed carbon in percentage present in which volatile matter percentage has its main components as carbon and hydrogen (Gunnamatta, 2016). A subsample of 100g was drawn from the original MSW sample from each of the dumpsites $S_{(Gosa)}$, $S_{(Dutse)}$, $S_{(Karshi)}$, $S_{(Kubwa)}$ in AMAC & Bwari area council. Subsequently, each subsample was sorted into different components representing the ratio percentage of the components in their original sample. The sorted subsamples with combustible features such as plastics, papers, food waste/organics, and textiles were used, leaving out the noncombustible components like ceramics and metals. Some other combustibles present in other waste such as diapers and sanitary pads (with pulp features); rubber; tiny pieces of wood/garden waste among others, were categorized under organics. Furthermore, the individual subsamples were weighed to validate their original weights in % as represented in the original sample. Again, all the sorted combustibles in the subsamples were mixed individually by their category for all the dumpsites, and the mean weight in percentage for each category was obtained to be used for the proximate analysis. The individual mean subsamples (for example, average of the mixed subsample for plastics in all the dumpsites) were placed in petri dishes and heated separately in oven (carbolite furnace) for 1 hour at 105°C to determine the moisture content and dry mass of each component in the MSW subsample. For an additional loss of weight, 50% of each category of dry mass of the mean subsample was placed in the crucible after the initial weight of the crucible had been obtained, and later reweighed before it was placed into the SXL-1200 °C benchtop Muffle furnace on ignition at 950°C for 30 min to determine the % volatile matter (dry basis) and % ash content. This process is referred to as the proximate analysis. The Eq. (1), (2), and (3) were used for the proximity analysis as it was demonstrated in Kuleape et al. (2014).

$$M = ((w - d)100) / w \qquad (1)$$

Where: M= wet-mass moisture content, %; w (kg) = initial mass of MSW subsample; d (kg) = mass of subsample after drying.

$$\% V_m = ((d_0 - w_0)100) / d_0 \qquad (2)$$

$$W_{(Ash)}\% = (w_0 * 100) / d_0 \qquad (3)$$

Where: V_m = % volatile (dry basis); $W_{(Ash)}$ = % ash (dry basis); d_0 = weight of dry MSW subsample; w_0 = weight of residue after ignition.

However, a similar approach was employed for the proximate analysis of Porto MSW, and the MSW used in for Porto characterization was obtained from waste bins in Gaia (Telheira and Mosteiro), and Porto city (Arca da Agua and Areosa). The furnace used to determine the % volatile matter (dry basis) and % ash content is 47900 thermolyze benchtop muffle furnace. The characterized data for Porto were merged into similar MSW category as that of Abuja to ensure uniformity in the study. The subsamples for Gaia S (Gaia) are ($S_{(Telheira)}$ and $S_{(Mosteiro)}$) while that of Porto city, $S_{(Porto\ city)}$ are ($S_{(Arca\ d\ Agua)}$ and $S_{(Areosa)}$). Therefore, the mean subsample S (Porto) is the average of the subsamples $S_{(Gaia)}$ and $S_{(Porto\ city)}$.

2.4. Ultimate Analysis

The ultimate analysis was used to estimate the percentage of carbon, hydrogen, oxygen, nitrogen, sulphur and ash present in the MSW sample. Provided the dry mass of each component in the MSW sample has been determined by the proximate analysis, hence, the elemental contents like; carbon, hydrogen, oxygen, nitrogen, sulphur and the ash content for waste sample can be determined using the standard table of ultimate analysis of combustible waste in (Tchobanoglous et al, 1977; and Chandrappa and Das, 2012). The table 1 shows the standard elemental value present in the combustible component to estimate the elemental content (Ec) as displayed in Eq. 4.

Table 1. Standard Elemental Composition % for Experimental Carbon contents & ratio of Elements.

MSW Category	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulphur (%)
Food Waste / Organics	48	6.4	37.6	2.6	0.4
Plastics	60	7.2	22.8	0.0	0.0
Paper	43.5	6.0	44	0.3	0.2
Textile	55	6.6	31.2	4.6	0.15

Source: Adapted from Tchobanoglous et al, (1977) and Othman (2008).

The elemental content can be estimated by the expression (see Eq. 4):

$$\text{Ec (kg)} = (\text{Dry mass} * \text{Standard element value}) / 100 \qquad (4)$$

Where: Ec = element content (C/H/O/N/S) values in the MSW components were obtained from the standard table of ultimate analysis of combustible waste. This was computed for each component present in the waste sample and cumulated to arrive at a (C, H, O, N, S) value ofthe sample, and subsequently it was substituted into the modified Dulong equation. The energy content (HHV value) of MSW can be determined by the modified Dulong equation (Tchobanoglaus et al, 1993) and it is expressed in Eq. (5) as:

$$\text{HHV (MJ/kg)} = 337C + 1419(H_2 - 0.125O_2) + 93S + 23N \qquad (5)$$

Where: C= Carbon (%), H= Hydrogen (%), O= Oxygen (%), S= Sulphur (%),

N= Nitrogen (%)

2.5. Calorific Value Estimation for MSW Energy Potential

For the consideration of an economic viable WTE project, it is imperative to evaluate the calorific measurement (i.e., energy output and the degree of combustion) of the MSW. The calorific value is classified into the Higher Heat Value (HHV) and Lower Heat Value (LHV). HHV is described as the quantity of heat generated by a complete combustion of a unit mass of sample in air or oxygen, such that the product of combustion cooled down to the room temperature and remains in liquid form (Franjo et al, 1992). However, LHV is the net heat produced when a unit mass of the sample is completely burnt in air or oxygen, such that the product of combustion can escape as steam. In this study, the LHV of the MSW sample was calculated (see Eq. 6) as it was done in Prasada Rao et al, (2010) as:

$$\text{LHV (kcal/kg)} = \text{HHV} - 9\text{H} * \text{LHS} \qquad (6)$$

Where: LHV = Lower Heat Value; HHV= Higher Calorific Value.

LHS = Latent Heat of Steam which is 587 (kcal/kg); H = Hydrogen (%).

2.6. Energy Recovery Potential and Power Generation Potential

In the case of energy recovery, thermochemical conversion utilizes all its organic matter, biodegradable as well as non-biodegradable for energy output. In addition, Tsunatu et al, (2015) in their research reported that the amount of energy recovered from MSW based on different conversion methods is a function of its calorific value and organic content. Therefore, the Energy Recovery Potential for the thermo-chemical conversion of MSW is expressed in Eq. (7) as:

$$\text{Erp (kWh)} = \text{LHV} * \text{Wt} * (1000/860) * \infty \qquad (7)$$

Where: Erp (kWh) = energy recovery potential of MSW sample.

LHV = Lower Heat Value; Wt = Weight of waste (tons).

∞ = Conversion Efficiency which ranges between 22 – 28% (IEA, 2007).

Also, it is important to establish Energy Recovery Potential for Erp $_{(\mathbf{Porto})}$ and Erp $_{(\mathbf{Abuja})}$ respectively is expressed as Eq. (8) and Eq. (9):

$$\text{Erp}_{(\mathbf{Abuja})} = \text{LHV}_{(\mathbf{Abuja})} * \text{Wt} * (1000/860) * \infty \qquad (8)$$

$$\text{Erp}_{(\mathbf{Porto})} = \text{LHV}_{(\mathbf{Porto})} * \text{Wt} * (1000/860) * \infty \qquad (9)$$

2.7. Comparative Power Generation Potential (Porto and Abuja)

The power generation potential (Qgp) is simply the amount of energy that can produce electric power supply or heat system daily (24 hours), and it is expressed in Eq. 10 as:

$$\text{Qgp (kW)} = \text{Erp} / 24 \qquad (10)$$

The comparison approach has the tendency of establishing a relationship between the Qpg $_{(\mathbf{Porto})}$ and Qpg $_{(\mathbf{Abuja})}$. Furthermore, the Qgp $_{(\mathbf{Porto})}$ and Qgp $_{(\mathbf{Abuja})}$ having known the Erp of both locations and by substituting Eq. (8) and (9) into Eq. (10). Therefore, Qgp is expressed as:

$$Qgp_{(Abuja)} = LHV_{(Abuja)} * Wt * 0.04845 * \infty \qquad (11)$$

$$Qgp_{(Porto)} = LHV_{(Porto)} * Wt * 0.04845 * \infty \qquad (12)$$

The evaluation the Qpg $_{(Porto)}$ and Qpg $_{(Abuja)}$ using the Wt of MSW repeatedly at intervals of 100 tons using Eq. (11) and Eq. (12) was employed. Furthermore, the evaluated results of Qpg $_{(Porto)}$ and Qpg $_{(Abuja)}$ were plotted against the different Wt at an interval of 100 tons starting from 100 tons to 2000 tons for the purpose of comparison. In addition, the per person daily generation of MSW was computed with the Wt to estimate the populations involved in MSW generation at equal Wt in Porto and Abuja using Eq. (13). Similarly, a comparative approach was also employed by plotting the estimated populations generating MSW in Porto, and Abuja against the equivalent weights in tons.

$$P = Wt \,/\, \text{per person daily generation of MSW}, \qquad (13)$$

Where: P is the estimated population generation MSW.

Wt = Weight of waste (tons).

3. Results

In this section, the displayed tables are results from physical analysis (MSW characterization), proximate and ultimate analysis, as well as the experimental results. The table 2 shows the mean characterization of MSW from field investigations for Abuja and Porto during the wet and dry seasons. Furthermore, the results of the characterization show that the components were categorized into two namely combustibles and noncombustible MSW (see table 2).

Table 2: MSW Characterization for Abuja & Porto into Combustibles & Non-combustibles

MSW Type	Mean (wet &dry) season MSW Abuja (%)	Mean (wet &dry) season MSW Porto (%)
Food waste/ Organics	49.38	39.08
Plastics	19.30	18.55
Paper	11.21	5.37
Textile	1.45	6.63
Non-combustibles	18.66	30.37

The table 3, 4, 5 and 6 shows that results of the experimental analyses (proximate analysis, and ultimate analysis). The proximate analysis shown in table 3 and 4 displays the moisture content

% in the wet mass of each waste type in the combustive waste stream, as well as the dry mass of the waste type.

Table 3: Abuja Proximate Analysis Result

Waste Type	Wet Mass (g)	Moisture Content (%)	Dry Mass (g)
Food waste/ Organics	49.38	45.99	26.67
Plastics	19.30	2.38	18.84
Paper	11.21	42.90	6.40
Textile	1.45	8.97	1.32

Table 4: Porto Proximate Analysis Result

Waste Type	Wet Mass (g)	Moisture Content (%)	Dry Mass (g)
Food waste/ Organics	39.08	22.95	30.11
Plastics	18.55	2	18.18
Paper	5.37	16.39	4.99
Textile	6.63	1.50	6.53

Table 5. Ultimate Analysis result of MSW Sample for Abuja

Waste Type	Wet Mass(g)	Dry Mass(g)	Moisture Content(g)	C(g)	H(g)	O(g)	N(g)	S(g)	Ash(g)
Food waste/Organics	49.38	26.67	22.71	12.80	1.71	10.03	0.69	0.11	1.33
Paper	11.21	6.40	4.81	2.78	0.38	2.82	0.02	0.01	0.39
Plastics	19.30	18.84	0.47	11.30	1.36	4.30	NIL	NIL	1.88
Textile	1.45	1.32	0.13	0.73	0.09	0.41	0.06	0.002	0.03
Total	81.34	53.23	28.12	27.61	3.54	17.56	0.77	0.12	3.63

3.1. *Calculating for* HHV *and* LHV.

In order to calculate the HHV and LHV, the estimated (C, H, O, N, S) data for Abuja in table 5 shows the total elemental content in a combustive MSW sample for Abuja. Given; C = 0.02761 kg; H = 0.003534 kg; O = 0.01756 kg; N = 0.00077 kg; S = 0.00012 kg. By substituting the (C, H, O, N, S) values in the modified Dulong equation (See Eq. 5).

$$\text{Therefore: } HHV_{(Abuja)} = 337\ (0.02761) + 1419\ (0.007068 - 0.00439) + 93\ (0.00012) + 23\ (0.00077)$$

$$HHV_{(Abuja)} = 13.13 \text{ MJ/kg}$$

Converting MJ/kg to kcal/kg; (1 MJ/kg =238.8459 kcal/kg)

$$\text{Therefore; } HHV_{(Abuja)} = 3136.05 \text{ kcal/kg}$$

$$LHV_{(Abuja)} = HHV_{(Abuja)} - 9H * LHS$$

Recall that the LHS = Latent heat of steam = 587 kcal/kg

$$LHV_{(Abuja)} = 3136.05 - 9\ (0.003534) * 587$$

$$LHV_{(Abuja)} = 3117.38 \text{ kcal/kg}$$

Table 6. Ultimate Analysis result of MSW Sample for Porto

Waste Type	Wet Mass(g)	Dry Mass(g)	Moisture Content(g)	C(g)	H(g)	O(g)	N(g)	S(g)	Ash(g)
Food waste/Organics	39.08	30.11	8.97	14.45	1.93	11.32	0.78	0.12	1.51
Paper	5.37	4.49	0.88	1.95	0.27	1.96	0.01	0.01	0.29
Plastics	18.55	18.18	0.37	10.91	1.31	4.15	NIL	NIL	1.81
Textile	6.63	6.53	0.10	3.59	0.43	2.04	0.30	0.01	0.16
Total	69.63	59.31	10.32	30.90	3.94	19.47	1.09	0.14	3.77

Also, to calculate the HHV and LHV, the estimated (C, H, O, N, S) data for Porto in table 6 shows that by using Dulong's Equation (see Eq. 5).

Given: C = 0.0309 kg; H = 0.00394 kg; O = 0.01947 kg; N = 0.00109 kg; S = 0.00014 kg.

Therefore: $HHV_{(Porto)} = 337\ (0.0309) + 1419\ (0.00788 - 0.00487) + 93\ (0.00014) + 23\ (0.00109)$

$$HHV_{(Porto)} = 14.72 \text{ MJ/kg.}$$

Converting MJ/kg to kcal/kg; (1 MJ/kg =238.8459 kcal/kg)

Therefore: 14.72 MJ/kg = 3515.81 kcal/kg

$$LHV_{(Porto)} = HHV_{(Porto)} – 9\ H * LHS$$

Where; LHS = Latent heat of Steam = 587 kcal/kg

$$LHV_{(Porto)} = 3515.81 – 9\ (0.00394) * 587$$

$$LHV_{(Porto)} = 3495 \text{ kcal/kg}$$

3.2. Estimating the Power Generation Potential (Q_{gp})

Recall that from Eq. (11):

$$Qgp_{(Abuja)} = LHV_{(Abuja)} * Wt * 0.04845 * \infty$$

$$= 3117.38 \text{ kcal/kg} * 100 * 0.04845 * 0.22$$

$$= 3322.82 \text{ kW}$$

$$= 3.32 \text{ MW}$$

Recall that from Eq. (12)

$$Qgp_{(Porto)} = LHV_{(Porto)} * Wt * 0.04845 * \infty$$

$$= 3495 \text{ kcal/kg} * 100 * 0.04845 * 0.22$$

$$= 3725.32 \text{ kW}$$

$$Qgp_{(Porto)} = 3.73 \text{ MW}$$

Table 7. Daily Power Generation Potential (Qgp) of Porto & Abuja MSW by weight (Wt) & Population.

S/N	MSW Weight Wt (tons)	Qgp (Porto) (MW)	Qgp (Abuja) (MW)	Population (Porto) @ 1.3kg/person daily	Population (Abuja) @ 0.76kg/person daily
1	100	3.73	3.32	76923	131579
2	200	7.45	6.66	153846	263158
3	300	11.18	9.97	230769	394737
4	400	14.90	13.29	307692	526316
5	500	18.63	16.61	384615	657895
6	600	22.35	19.94	461539	789474
7	700	26.08	23.26	538462	921053
8	800	29.80	26.58	615385	1052632
9	900	33.53	29.91	692308	1184211
10	1000	37.25	33.23	769231	1315790
11	1100	40.98	36.55	846154	1447368
12	1200	44.70	39.87	923077	1578947
13	1300	48.43	43.20	1000000	1710526
14	1400	52.15	46.52	1076923	1842105
15	1500	55.88	49.84	1153846	1973684
16	1600	59.61	53.17	1230769	2105263
17	1700	63.33	56.49	1307692	2236842
18	1800	67.06	59.81	1384615	2368421
19	1900	70.78	63.13	1461539	2500000
20	2000	74.51	66.46	1538462	2631579

Table 7 shows the estimated Qgp (Porto) and Qgp (Abuja) at weight intervals of 100 tons (100 …. 2000 tons) of MSW. From table 7, the comparison made between the power generation potential Qgp (Porto) and Qgp (Abuja) was found to be at a ratio of **1: 0.89**. Furthermore, the table 7 also shows that the estimated number of people generating MSW for Porto and Abuja daily using the Eq. 13. The estimated results were compared, and it was observed that the ratio of the population generating MSW for Porto and Abuja was found to be at **1: 1.71.** Again, the graphical representation in fig. 6 showed the Qgp for Porto, and Abuja increases parallel to one another at equivalent weights. In addition, the graphical representation in fig. 7 showed that people generating MSW for Porto and Abuja daily increases parallel to one another at equivalent weights.

However, it was observed that the population gap of Abuja generating equivalent weights of MSW is about twice of that of Porto.

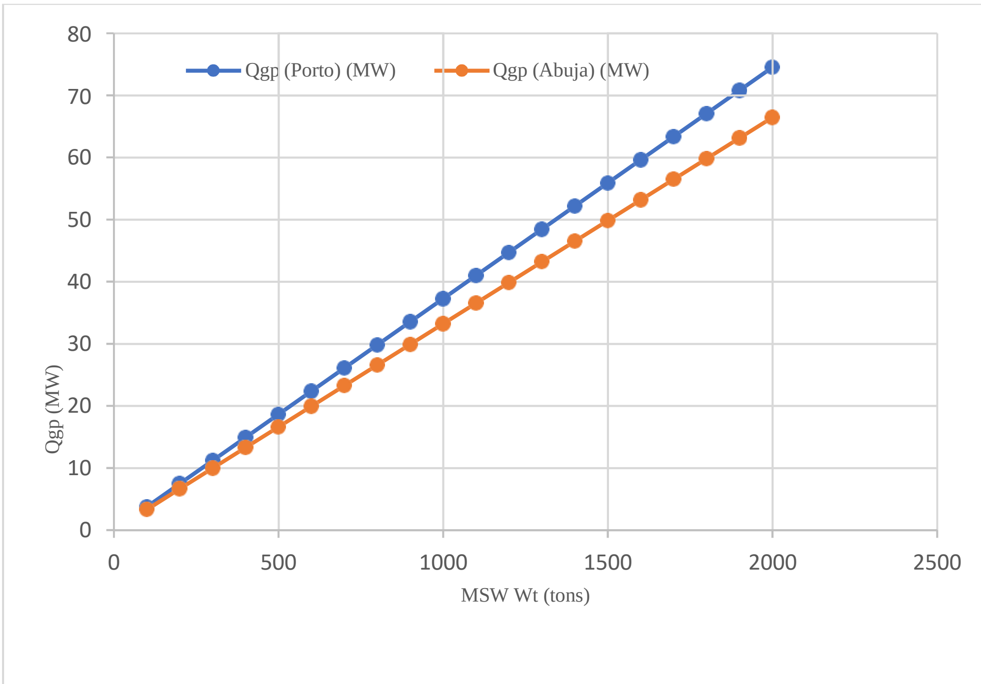

Fig. 6: Power Generation Potential (Qgp) of Porto & Abuja MSW by Weight (Wt).

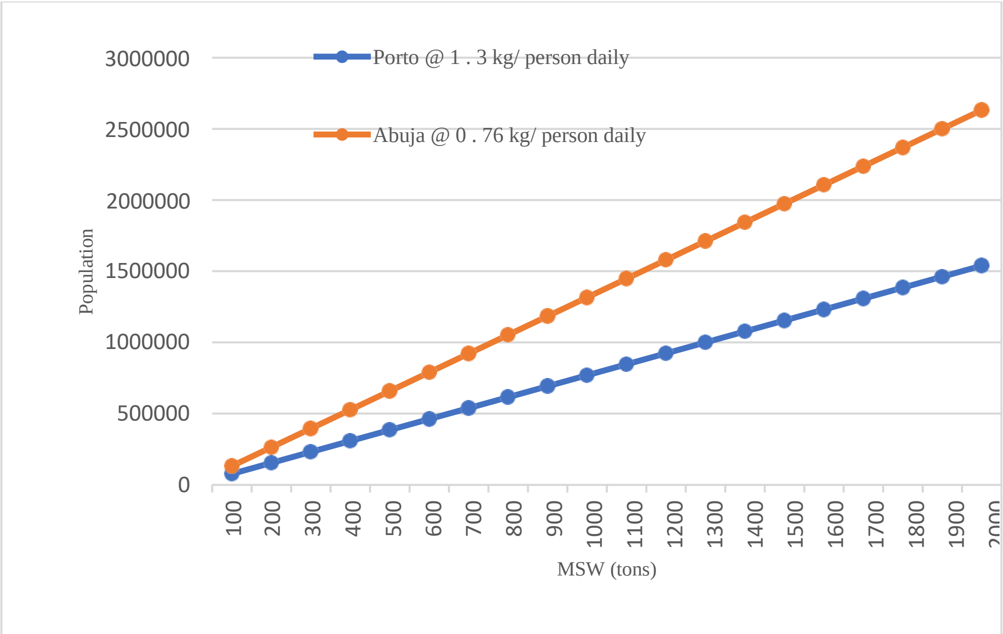

Fig. 7: Abuja and Porto MSW generation per Population.

4. Discussion

The lifestyle, socio-economy, and level of income among others have a strong influence on the type of MSW generated within communities. However, its percentage composition varies from one country to another. Studies such as Franjo et al. (1992), Menikpura et al. (2007), Sivapalan at al. (2003), and Kuleape at al. (2014) used bomb calorimeter to estimate the calorific values present in MSW components for electrical power and heat supply. However, these studies did not carry out a comparative study between cities with one having an existing WTE facility. This study demonstrates a general understanding and common MSW composition of Porto, Portugal and Abuja, Nigeria. Table 2 shows the mean results of the MSW characterization in both dry and wet seasons combined for the two study areas, with the focus of interest is on the combustible components of MSW. However, other components such as metal, ceramics among others were classified as non-combustibles. The MSW type in Porto was adjusted to same category of MSW type in Abuja to ensure uniformity. From table 2, certain components such as plastics and paper in the combustible components in Porto MSW do not totally represent the actual data as a result of the waste segregation in the eco-point waste bins designed to accommodate specific recyclable materials. The results in table 2 show that food waste/organic has highest % in both Porto and Abuja.

The physical analysis done on the Abuja MSW in different seasons (dry and wet) shows that the mean results have combustible components of about 81.35% (see table 2). However, from table 2, it was observed that the summation of the moisture content present after being subjected individually to heat at 105ºC for 1hour in the oven was 34% of the total mass of combustible components in the sample. Hence, the remaining dry mass was estimated to be about 65.44%. The dry mass was used in the evaluation of the elemental ratios (C, H, O, N, S) for the estimation of the HHV(Abuja). Also, from table 3, it was observed that the summation of the moisture content present after being subjected individually to heat at 105ºC for 1 hour in the oven was 22.94% of the total mass of combustible components in the sample. In Porto, the practice of utilizing MSW for energy production has been established for over a decade, and it is being carried out by companies such as; Lipor (incineration with energy recovery), and Suldouro (landfill gas to energy). This is simply an indication that the MSW in Porto has the potential of producing enough energy for domestic use.

From the proximate analysis experiment, tables 3 and 4 show the result obtained and it was deduced that the moisture content plays a significant role in the estimation of the amount of Carbon; Hydrogen, Oxygen, Nitrogen, and Sulphur of individual MSW types in order to determine the energy output. It was clear that the moisture content in the food waste/organic (45.95%) and paper (42.90%) was higher in Abuja MSW when compared with Porto at food waste/organic (22.95%) and paper (16.39%). However, the MSW in Porto are usually not kept in open bins or dumped in open fields. Unlike in Abuja where the reverse is the case. Also, it was deduced that plastics generally recorded low moisture content for Abuja and Porto at 2.38% and 2% respectively. The derived elemental composition % (see table 1) using experimental carbon content and ratios of elements given by Tchobanoglous et al, (1977) was used to obtain the higher calorific value (HHV) for individual MSW category in Porto and Abuja. However, the elemental composition % was computed with the dry mass each MSW category for Porto and Abuja to obtain the actual mass of the elemental composition in each waste type (see table 6). The summation of these elemental composition in mass for the MSW was employed in the modified Dulong formula to estimate the HHV.

Using Eq. 5, the values of HHV calculated for the Abuja and Porto MSW were 3136.05 kcal/kg and 3515.81 kcal/kg respectively. However, for a feasible energy output for power generation, it is important that the product of combustion is in form of steam which represents the LHV. In addition, it is imperative to know the value of the HHV to determine the value of the LHV (see Eq.

6). From (Eq. 6), the values of LHV for Abuja and Porto were evaluated as 3117.38 kcal/kg and 3495 kcal/kg respectively.

To obtain the Qgp of MSW, it was expedient to estimate the Erp (Porto) and Erp (Abuja). The Erp itself was estimated using Eq. 7 with variables such as LHV, to be calculated; conversion efficiency (∞), which is a constant variable which varies from 22% - 28%; and Wt, which was the weight of the MSW utilized. For this study, the varying weights were employed in the comparative study to estimate the possible energy output according to the quantity of MSW fed into the WTE plant to produce energy. Hence, Weight of MSW at intervals of 100 tons (100 tons, 200 tons, …. 2000 tons) was utilized for the estimation of Erp (Porto) and Erp (Abuja). Again, there are other factors such as moisture content and the MSW composition type that contribute to the energy output. This study has considered these factors and it has used the lowest conversion rate of 22% due to the efficiency of the quality of the MSW used as fuel, and the type of WTE plant employed. From the results obtained while estimating the Erp (Porto) and Erp (Abuja), it was deduced that the energy generated was on hourly basis, and to determine the Qgp, the Erp values obtained were divided by 24 hours using (see Eq. 10) in order to quantify the energy output from MSW in Porto and Abuja on daily basis (see table 7). In addition, the study further utilized the Wt and individual daily generation of MSW for Porto and Abuja at 1.3 kg/person daily, and 0.76 kg/person daily to estimate the total number of persons generating these MSW (see table 7).

In order to establish a comparison between the power generation potential Qgp in Porto and Abuja, by utilizing their MSW as fuel in WTE technology, the Qgp (Porto) and Qgp (Abuja) was plotted against weights (Wt) at intervals of 100 tons (100 tons, …. ,2000tons) as shown in fig. 6. It was discovered that there is no mathematical relationship between the Qgp (Porto) and Qgp (Abuja) as the graph (see fig 6) for the Qgp for both cities are parallel to each other against equivalent weights of MSW. Since the power generation potential Qgp was subjected to the same MSW weight (Wt) at regular intervals, it was observed (see table 7) that the ratio of the power generation potential of Porto Qgp (Porto), and Abuja Qgp (Abuja) was found to be **1: 0.89**. Again, the ratio of the population generating these equivalent weights (Wt) of MSW at per person daily generation for Porto and Abuja is **1: 1.71.** Moreover, it is clearly shown in table 7 that the per capital daily generation of MSW in both Porto, and Abuja are 1.3 kg/capita/day, and 0.76 kg/capita/day respectively. Also, fig. 7 displays a linear graph indicating that the increase in the population of Abuja contribute immensely to the generation of MSW in the city. However, the financial indication of managing such generation of MSW is limited likewise the manpower, environmental and public health challenges associated with this increase is of great concern.

Hence, an adoption of WTE technology for power generation in Abuja will be a sustainable concept since the monthly collection data in 2014 shows a huge quantity of MSW is collected by AEPB controlled areas only (see fig. 2). The problem of low coverage in the collection of MSW in Abuja is still a big issue. However, an effective collection is likely to enable the use of waste as fuel for electricity. With regards to pollution from the emissions, currently, there are excellent innovations in terms of emission control systems that deal with the reduction of greenhouses gas and another toxin to the emission standards at 1990 level of United Nations Framework on Climate Change (UNFCC) and International Panel for Climate Change (IPCC).

5. Conclusions

The physical, proximate, and ultimate analyses were done for the MSW in Porto, Portugal and Abuja, Nigeria. From the results of physical analysis, it was observed that food waste /organics was of higher percentage in both study area**s** when compared to the rest of the MSW types. It was also observed from the proximate analysis that the moisture content in the MSW in Abuja is higher than that of Porto as a result, there was a reduction the calculated higher calorific values (HHV) and net calorific values (LHV). The LHV remains very significant in the estimation of the power generating potential Q_{gp} for the study areas using varying weights Wt at regular intervals, and it was deduced from the result that the $Q_{gp\ (Porto)}$ is higher than $Q_{gp\ (Abuja)}$ due to the moisture content factor and the constituent of the MSW. Also, a comparative analysis employed shows that the population in Abuja generates almost twice the MSW in weights as the population in Porto. This simply shows that the high and increasing population growth in Abuja is perceived to be an advantage. More so, a higher quantity of MSW will be generated by the inhabitants to be used as fuel to improve the $Q_{gp\ (Abuja)}$ with the knowledge that its MSW possess highly combustible components. There is a clear limitation on the effect of moisture content in this study regarding the MSW in Abuja; however, the proper covering of the waste bins and the used of mechanical aeration technologies after collection is likely to improve the quality of waste to the used as fuel in a WTE technology.

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6.

Conclusions and Recommendation

6.1 Conclusions

Nigeria is a wealthy nation but likely to be the country with the lowest power supply to its citizens in the world. Notwithstanding, the citizens are still hopeful for improvement. As the need for alternative energy grows, this study investigated the combustible MSW in Abuja (AMAC and Bwari area council), Nigeria to ascertain the power generation potential locked up in waste streams. The study adopted some aspects of the integrated waste management strategies to arrive at desirable results. The study employed procedures like geospatial techniques, statistical analyses, empirical analyses, and arithmetic calculations to attain the principal goal.

The study designed a conceptual framework for outreach and education of the society on the perception, discipline, and merits of MSW in the environment. It was perceived that this framework is likely to help disseminate environmental education and create awareness in the society to enable the citizens to halt the practice of indiscriminate waste disposal. It also identified suitable channels used by principal actors (government, NGOs, private organizations, traditional rulers, public groups) to propagate information to society through easy and practical procedures.

Also, the utilization of geospatial technologies and ICT for solid waste management and monitoring have the competence of improving the total collection coverage, reduce cost and time of transportation, and adequate disposal to designated sites. However, this approach is likely to achieve merits such as building baseline data for solid waste management; eco-friendly society; and planning and budgeting.

The integration of GIS and multi-criteria evaluation have been proven justifiable for the location of suitable sanitary sites in AMAC and Bwari area council, Abuja. It was deduced that the criteria adopted from the Ireland EPA manual for siting a sanitary landfill is best suitable for Abuja and Nigeria at large as compared to the deficient World Bank criteria due to the settlement pattern. Spatial and non-spatial data was integrated into the GIS (ArcGIS 10.1) software where spatial analysis and weighted overlay analysis were carried out. As a result, 6 highly suitable sites were identified for a landfill facility. However, 4 sites were preferred due to land size availability and non-intersection with the sensitive land use present in the study area.

Again, this study inferred that physical analysis (waste characterization) of MSW is imperative in any WTE project so that it is possible to distinguish between the combustibles and non-combustible MSW. However, the MSW of Porto was adjusted to the categories of the Abuja MSW to maintain uniformity in the category of their MSW. The statistical analysis showed that food waste /organics is the predominant type of MSW in Abuja and Porto. The focal point of the MSW characterization in the study are the combustibles present in the waste stream of both cities and, the results from the proximate and ultimate analyses were used to estimate the higher calorific value (HHV) or gross calorific value (GCV) and lower calorific value (LHV) or net calorific value (NCV). However, the proximate analysis showed that the moisture content in the MSW in Abuja is higher than that of Porto, therefore, influences the calculated higher calorific values (HHV) and lower calorific values (LHV). The power generation potential Pgp (Qgp) was estimated based on the calculated LHV for both cities.

Lastly, the comparative analysis showed that the Pgp (Porto) derived from the combustible waste stream in Porto is higher than the Pgp (Abuja) derived from the combustible waste stream in Abuja. However, the moisture content, and the constituent of the MSW in these cities played a significant role in this context. Again, based on per capita generation of MSW daily of both cities, the population in Abuja generates almost twice the MSW in weights as the population in Porto.

6.2 Recommendation

The government should embark on sustainable energy policies that are likely to contribute toward other societal and economic development objectives. Again, the authorities and relevant stakeholders must continue to work assiduously in the aspect of outreach and education by conveying the message of MSW disposal ethics and management to the populace. The authorities must do their fair responsibility by providing basic infrastructure and deployment of new technologies for the management of MSW in the communities. The authorities should look across policies to maximize positive synergies to ensure implementation and enforcement of environmental laws to propagate the need for the populace to participate actively and act responsibly towards proper waste disposal and management in their communities.

In a way to bridge the gap of energy shortage in Nigeria, the government should develop indigenous renewable energy resources which will simultaneously reduce local forms of pollution. Also, the authorities and relevant stakeholders should see Waste to Energy (WTE) as an opportunity and a solution to supplement power generation and distribution in the Nigeria. In addition, the concept of WTE is likely to improve the environment in the aspect of waste recycling, reduce landfilling, as well reducing the health-related problems associated with waste disposal in the community.