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TOWARDS A FRAMEWORK FOR THE ADOPTION OF SMART URBAN WASTE MANAGEMENT SYSTEM: A CASE STUDY OF THE FEDERAL CAPITAL TERRITORY, ABUJA

Master's thesis

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ABSTRACT

Smart waste management is a collection of technology, process, and people towards efficient waste management throughout the waste lifecycle. While solid waste management is a global concern, it is a precious asset if appropriately managed. The overall success in its management could entail progress and signify a level of a city's maturity. Therefore, different nations are making efforts toward digitisation for efficient waste management. This research was motivated by the growing challenge of solid waste management in Abuja. The main research question that guided this study was 'How to improve the Abuja waste management system using smart waste management system?'. The methodology undertaken was a case study of Abuja aimed to suggest a framework for smart waste management. With specific objectives clearly stated, a thorough analysis of waste management practices prevalent in Abuja was conducted through interviews with residents and waste management administrators. A set of semi-structured guided questions were developed. Findings revealed three common waste management practices: burning of waste, illegal dumpsites, and approved dumpsites. Other issues identified include administrative bureaucracy that characterises the Federal Capital Territory Administration (FCTA), inadequate funding, and lack of compliance due to weak regulatory enforcement. However, most of the stakeholders identified in this study were concerned about the current waste management practices. They support a system that could not only improve waste management processes but could create a cleaner environment. As identified by interviewees, this process should involve residents as co-creators from the planning to the implementation stage. At the end of the research, the author formulated a framework for the adoption of smart waste management system in Abuja, which is the main contribution of this study.

Keywords: Smart city, Smart waste management, Urban management, Smart city

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LIST OF ABBREVIATIONS AND TERMS

AC	Area Council
AEPB	Abuja Environmental Protection Board
AI	Artificial Intelligence
AMP	Abuja Master Plan
CIA	Central Intelligence Agency
DES	Department of Engineering Services
ERGP	Economic Recovery and Growth Plan
FCC	Federal Capital City
FCDA	Federal Capital Development Authority
FCT	Federal Capital Territory
FCTA	Federal Capital Territory Administration
GIS	Geographical Information System
GSM	Global System for Mobile Communication
GPRS	General Packet Radio Service
GPS	Global Positioning System
IBM	International Business Machines
ICT	Information and Communication Technologies
IoT	Internet of Things
ISWM	Integrated Sustainable Waste Management
JICA	Japan International Cooperation Agency
MSWM	Municipal Smart Waste Management
RFID	Radio Frequency Identification
RS	Remote Sensing
SC	Smart City
SCADA	Supervisory Control and Data Acquisition
ST	Satellite Town
STDD	Satellite Towns Development Department
SWM	Smart Waste Management
SWMS	Smart Waste Management System
VHFR	Very High Frequency Radio

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INTRODUCTION

Solid waste management is a significant challenge bedevilling rapid urbanising cities, especially in developing countries (Diaz et al., 2005; Di Bella et al., 2011; Guerrero et al., 2013). As cities regularly experience an influx of people, additional burdens are added to the already existing infrastructures. These burdens include but are not limited to water treatment plant, sewages, houses, markets, utility services, and security outfits (Manshanden and Lambooy, 2003; Marceau, 2008), thereby creating a necessity for improved facilities to accommodate these demands (Chourabi et al., 2012).

These rising concerns are also the case of Abuja, the capital city of Nigeria. Unlike other cities within the country, this city has a detailed and, to a large extent, well-followed master plan. Before Abuja became the nation's capital, Lagos state was the then capital city whose capability to retain the capital city was a significant concern. This concern resulted from Lagos infrastructural deficits such as congestion (Adeponle, 2013; Wapwera, 2015; Amusa et al., 2017). As a response, the Nigerian Government commissioned a consortium in 1975 to design a new capital from a savannah, a total neutral ground devoid of rancour claiming ownership or original settlers (Bons et al., 2018). With the infrastructure systematically planned, the capital city faces an infrastructure deficit resulting from population explosion as the original master plan had a target population of about three million (Bons et al., 2018).

With the urbanisation rate of 8.32% per year in Abuja, making it the fastest-growing city in Africa (Myers 2011 cited in Amusa et al., 2017; Amusa et al., 2017), the city faces many populations triggered challenges. One of the global challenges faced due to urban population growth is solid waste management (Amasuomo et al., 2015). The country has an annual solid waste production of 1.3 billion tonnes, and it is expected that by 2025 the solid waste generated will reach 4.3 billion tonnes, equivalent to half of the world's population (Hoornberg and Bhada-Tata, 2012). As the volume of waste generated experience exponentially increases, it outgrows city administrators' ability to improve on the technical and financial resources needed to handle this challenge (Kadafa, 2017).

Solid waste management challenges, which are occasioned by rural-urban migration, illegal building in contravention to the Abuja Master Plan (AMP) and change in consumption pattern (Zamorano et al., 2009; Kadafa, 2017), places extreme pressure on cities existing infrastructure

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(Misra et al., 2018; Manshanden and Lambooy, 2003; Marceau, 2008). According to Chourabi et al. (2012), these environmental challenges resulting from solid waste create a necessity for improved facilities to accommodate the demand. As the growing need for solutions arises, studies have proposed different approaches for a public service provision of Municipal Solid Waste Management (MSWM). These differences exist even though cities worldwide face the same challenges (Bel, Dijkgraaf and Fage, 2010; Plata-Díaz et al., 2014). Cities uniqueness in economic and socio-political landscapes (Wassenaar, Groot and Gradus, 2013; Plata-Díaz et al., 2014) informed these various approaches. Those pathways adopted by cities administrators are focused on restructuring their solid waste management services with the end objective of sustainability (Fuss et al., 2018).

Smart cities are identified as providing solutions to solving issues with the aid of intelligent technologies such as Artificial Intelligence (AI), 'Internet-of-Things' (IoT), cloud computing, cyber-physical and big data (Esmaeilian et al., 2018; Zhang et al., 2019). The term smart waste management has been used indiscriminately in several scholarly writings with no clear definition of the concept (Glouche et al., 2014; Schafer, 2014; Omar et al., 2016; Zhang et al., 2019). Nevertheless, Zhang et al. (2019) define smart waste management as the utilisation of smart enabling technologies toward providing an effective and efficient mode of sustainable operations of waste. According to the authors, the use of smart technologies such as big data analytics and cyber-physical systems can promote efficient monitoring, generation, collection, and transportation of waste for proper disposal and value retrieval (Zhang et al., 2019). While definitions of smart waste management are focused on using technology in waste management, proponents of integrated sustainable waste management argue that in conceptualising smart waste management, the local contents of three dimensions (technological, sustainability, and stakeholders) should be considered. This thesis seeks to bring to fore the functional characteristics of Abuja.

Many developed countries worldwide are taking advantage of this concept as a new approach toward urban development by upgrading existing cities despite the smart city concept's notation as a ‘buzz term’ (Agbali et al., 2019). According to Ikoku (2004), central to the Abuja Master Plan (AMP) principle is that the available infrastructures provided are expected to be at optimal functionality at all times. While the efficiency of available infrastructures is not the case today, it is common to see waste along waterways, streets, and storms drain gullies and public places (Kadafa, 2017). When conceiving smart city initiatives, the characteristics of a given city, such as

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the physical environment, financial capacity, organisational structure, and socio-economic context, should be considered (Caniato et al., 2014; Myeong et al., 2018). These initiatives may be conceived and implemented either on a large scale as practised in some advanced nations or on distinctive scales. Smart city initiative in this research is focused on smart waste management.

Smart city initiatives implemented by the Nigerian Government includes the Abuja Centenary City launched in 2014 and the Nigerian Smart City Initiative in 2017 (Mansur, 2019). However, not much is known about any smart waste management initiative led by the Federal Capital Territory Administration (FCTA) or its agencies, which is the focus of this research. Therefore, this thesis's motivation emanates from the Abuja urbanisation challenge, while contextualising a smart city initiative as a potential application for improving urban waste management, from waste generation to disposal. This thesis aims to create a framework that would guide the adoption and implementation of a smart waste management system, with Nigeria's nation capital Abuja as a case study. Abuja's choice as a case is owed to the fact that Abuja was planned to be an efficient city with unique characteristics compared to other major cities in Nigeria. Along with two sub research questions, the following research question was formulated to guide this research:

RQ: How to improve the Abuja waste management system using smart waste management system?

SRQ1: What are the current practices of urban waste management in the Federal Capital Territory?

SRQ2: What factors could hinder the adoption of smart waste management in the Federal Capital Territory?

To achieve the research aim of proposing a framework for smart waste management in Abuja, the specific objectives are as follows:

1. Analyse the current Abuja master plan and the prevalent waste management practices within the Federal Capital Territory.
2. Identify the unique roles of stakeholders in the pursuit of a sustainable waste management system.

To achieve this research object, which is to develop a framework for adoption of smart waste management system in Abuja, a single case methodology was adopted. As part of the steps in this research, data triangulation was adopted to ensure validity of the multi-sources of data (Carter et al., 2014). This process entailed analysis of the Abuja Master Plan about waste management, reviewing executive summary reports, unravelling the prevailing waste management practices, and

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conducting 13 one-on-one interviews with Abuja's waste management administrators and residents.

The remainder of this study includes a review of literature on smart waste management to understand the mechanisms behind the technical and social contexts. After that, the methods and procedures adopted for this research are stated and its choice justified. The next chapter contains a detailed case description as carried out and presents the results of the findings. Another chapter contains a discussion of findings, which leads to a proposed framework for adopting smart waste management system (SWMS). Lastly, the concluding part of this research contains recommendations for future work.

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2. LITERATURE REVIEW

This chapter seeks to provide scholarly definitions of different concepts in this research topic, such as smart city, urban management, and smart waste management. This section provides the background of the literature, necessary and fundamental in understanding related studies through detailed analysis. This chapter also presents the conceptual framework adopted for this research.

2.1 The concept of Smart City

Smart city is often regarded as equivalent only to Information and Communication Technologies (ICT) driven (Zubizarreta et al., 2015), as various authors define the concept from their perspectives. According to Musa (2018), a smart city utilises technology in providing answers to activities in the city. Smart city is the collection and application of smart computing technologies on essential facilities and services of a city (Washburn and Sindhu, 2010).

From another point of view, Nilssen (2019) argued that technology is not the only defining feature of a smart city but a means towards improvement (Angelidou, 2015). Also, Caragliu, et al. (2011) described a smart city as "when investments in human and social capital and tradition (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" (Caragiu et al., 2011, 50). While there is no universally accepted definition of smart city, there are several dimensions, as proposed by Giffinger and Pichler-Milanovic (2007), which form the basis of measuring smart cities. These are smart economy, smart people, smart environment, smart governance, smart living, and smart mobility (Giffinger et al., 2007).

With varied perspectives which characterise a smart city, Meijer and Bolívar (2016) discovered from their analysis the variation of emphasis by different authors on smart technology, human capital, and open governance. Their literature emphasises ICT as the defining features that strengthen the urban system (Meijer et al., 2016). Furthermore, Giffinger and Gudrun (2010) suggest that for nations with the desire to forge a long-term development, the state needs to own other resources in addition to ICT, such as human resources. Various scholars have postulated that one key variable of a smart city is its ability to generate economic growth (Hollands and Hollands,

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2008; Lee et al., 2014; Kabir and Owolabi, 2019; Masik et al., 2021). In turn, this growth may pose a conflict of interest or even hinder the other characteristics embedded in a smart city, such as the environmental impact in urban development (Shelton et al., 2014).

Arguably, the smart city (SC) concept is multi-dimensional in city development. The three identified elements of SC namely: technology, human resources, and participatory governance, interact to increase quality and sustainable environment (Nilssen, 2019). Based on the smart city concept's identified elements, Nilssen (2019) sum up that the concept denotes a "collection of developmental features" (Nilssen 2019, 100), which links a wide range of pre-existing components. Smart city initiative requires a good understanding of approaches available for its implementation (Wolfram, 2012). The author identified two main approaches: the triple-helix model and the open innovation eco-system, which he termed as complementary in terms of scale to be addressed and the stakeholders involved (Wolfram, 2012).

The triple-helix model: The triple-helix model of innovation was borne out of the interaction between innovation systems research with knowledge production, which focuses on the interaction between universities, industries, and Government to foster social and economic development (Shin and Shin, 2002). Originally, the triple-helix model was birthed as a means of measurement and evaluation of the level of smart cities in comparison with another city (Lombardi et al., 2011), it has since metamorphosed into a framework for the understanding of knowledge innovation systems and add up the multiple reciprocities which exist between the three factors (university, Government, and industries) while creating and maximising knowledge (Lombardi et al., 2011). However, ICT is deemed essential in these interactions to facilitate these processes through exchange platforms (Wolfram, 2012).

Open innovation eco-systems: As against the method of the triple-helix model of "creation of an urban-regional governance framework and practices" (Wolfram, 2012, 171), that drives growth. Open innovation eco-systems entails the transfer of knowledge between multiple stakeholders aimed at innovating products and new ways of service delivery (Bacon et al., 2019). Open innovation emphasises real-life issues identifying and designing new products and infrastructure in the settings' context (Leydesdorff and Deakin 2011; Durst and Poutanen, 2013).

Open innovation concept draws from the heterogeneity of concepts and approaches such as 'open innovation', 'lead-user involvement', 'crowdsourcing' or 'participatory design' as the actors

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involved purposively attract and benefit from diverse knowledge by making the innovation processes open (Chesbrough et al., 2008). In addition to the interactive environment, open innovation requires technological infrastructures, need-based partnership and a supportive environment for iteration and learning (Leydesdorff and Deakin, 2011).

Open innovation eco-system, in addition to the agglomeration of academia, Government, and business co-opt citizens and civil societies in the context of certain end users' group in the design and implementation of smart city initiative (Rubens et al., 2011; Leydesdorff and Deakin, 2011). The design of this model runs through loops of needs and analysis, evaluation and re-evaluation of design characterised by ‘openness’ as users are involved, ‘realism’ as it focuses on real-life issues, and ‘empowerment’ of users (Bergvall-kåreborn and Stahlbröst, 2011).

2.2 Smart Urban Management

Urban management has been used in the past contextually without aggregated meaning as it means different things to different actors (Mattingly, 2020). In his theory and practice of urban management in developing countries, Dijk (2006 in Baclija, 2011) defines urban management as the effort of incorporating public and private stakeholders in tackling major urban problems. Further expanding on his theory, Dijk (2008) sees urban management as "Local authorities focus on the major issues identified by the population and pay attention to the most important problem" (Dijk 2008, 8). Ensuring sustainability in urban development management entails various eco-friendly changes, which serve as better alternatives both economically and socially (Wong et al., 2006). According to Willis (2001, in Wong et al., 2006), central to the effective management of the urban area for sustainability requires knowledge of and integrating a city's cultural values. Making an urban setting more competitive, equitable, and sustainable by incorporating public and private actors in managing and solving urban issues is an integral part of urban management (Dijk, 2008; Zenker and Farsky, 2013). In recent times, the transformation of human urban living has been fuelled by technology's infusion in all spheres of human endeavours (Yigitcanlar, 2015). This could be evident in the utilisation of technological innovations for the planning and development of urban spaces (Shin and Shin, 2012).

According to Hoe et al. (2014), the inability of the traditional urban space to meet up with the growing demand occasioned by urban congestion brought about the need for the development of

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cutting-edge technologies such as high-performance computing systems, high-speed communication networks, and low power sensing technologies capable of making a city smart. According to the authors, some of these urban technologies are smart power grids (renewable power source and real-time energy cost management), structural and surveillance application capable of automating building management processes, transportation and traffic management, quality of food and water monitoring, and accessible healthcare applications (Hoe et al., 2014).

With the rising scholarly interest in urban management, advocates of the utilisation of smart urban technologies in city management of infrastructures such as energy, transportation, waste and water management favour the perceived effectiveness and potential of such application in megacities (Bulu et al., 2014), as well as communities (Holland, 2008). In exploring critical urban infrastructure systems that are essential, and has to be provided and managed, such as energy, water, transport, communication, waste, and building, Newton (2012) views urban technology development as leading to a socio-technical transition to an eco-friendly environment.

2.3 Smart waste management

Using static routes and schedule for waste collection is not an efficient approach in solving waste problems today. According to (Saha et al., 2017), smart waste management utilises solar-powered smart bins with the capacity of compacting and transmitting waste fullage information to the cloud. According to the authors, the embedded sensors monitor the level of waste accumulation and automatically compact the waste, thereby increasing the bin's capacity to hold ten times more than a regular bin. Similarly, (Zackarias and Sangeetha, 2018) poised that IoT based waste management provides a solution to the increasing challenge of effective waste management. According to the authors, this solution provides intelligence to waste bins by giving it the ability to detect whether the bin is filled or not, communicate with the server to find the best route to these locations and provide navigation to the truck drivers.

With scholars advancement on ways to improve municipal waste management, Aazam and Lung (2016) proposed cloud-based Smart Waste Management (CloudSWAM). Accordingly, separate bins are provided for different categories of waste, such as plastics, metals, and organic waste. Each is embedded with sensors that transmit its status to the cloud and other stakeholders connected within the eco-system. A determining feature of understanding a solid waste management system's strength and weakness is to analyse and integrate various factors (Caniato et al., 2014). According to the authors, social network analysis (SNA) and stakeholder analysis (SA) are better ways to understand the prevalent methods of waste management, stakeholders' roles, and challenges.

While technologies are applied in smart waste management (SWM), the integrated sustainable waste management (ISWM) brings to bear the need to consider the human factor in addition to technological and institutional factors while considering operationalisation of solid waste system (Klundert and Anschutz, 2001). According to Wilson et al. (2013), "effective and affordable systems are tailored to local needs and conditions, developed with direct involvement of service beneficiaries" (Wilson et al., 2013, 52).

Stakeholders involvement in all processes of systems adoption has experienced increased attention including in developing countries. According to Lohri et al. (2013), the involvement of stakeholders and experts in agreeing and prioritising which aspect of the services at a time is essential in achieving set goals. In global waste management practices, the siting of SWM disposal or treatment plant is a very complex process of decision-making that involves political leaders and other stakeholders (De Feo and De Gisi, 2010). The patterns of priority between both technical and non-technical stakeholders, using Analytical Hierarchy Process (AHP) (De Feo and De Gisi, 2010; Bao et al., 2012) with the possibility of using Geographic Information System (GIS) for spatial data analysis to ensure objectivity of choice (Moeinaddini et al., 2010; Tavares et al., 2011) are relevant studies justifying the need for active stakeholders involvement.

2.3.1 Information and Communication Technology and its applicability

With the rising need for effective and efficient waste management processes, ICT is increasingly becoming indispensable due to its abilities in data acquisition automation, recognition, transmission, depository, and analysis (Hannan et al., 2015). The authors categorised technologies involved processes from waste monitoring to disposal into four. These technologies include "spatial technologies, identification technologies, data acquisition technologies and data communication technologies" (Hannan et al., 2015, 511), as shown in Appendix 5 and described in the next paragraphs.

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Spatial technologies

Spatial technologies are central for adoption and usage about understanding the earth's surface through environmental modelling, analysis and studies in ways that were not possible before the advent of computer (Hannan et al., 2015; Milla and Lorenzo, 2005). These technologies can process complex spatial data and enhance the possibility of integrating diverse interfaces and models (Hannan et al., 2015). These technologies are categorised into three main types, which are the (GIS) global information system, (GPS) global positioning system, and (RS) remote sensing (Hannan et al., 2015; Zurmotai, 2016; Milla and Lorenzo, 2005).

- **GIS:** Geographic information system, also known as Geospatial information system, is a computer-enabled information system that has the capability of collecting, manage, integrating, analysing and displaying data in a map-like form (Hannan et al., 2015; Zurmotai, 2016; Milla and Lorenzo, 2005). GIS functional areas includes but not limited to sales analysis, weather forecast, land use planning, and population forecast. These areas enable spatial data production, management, cartography, and smart waste management system (Lu, Chang and Liao, 2013; Zurmotai, 2016).
- **GPS:** This is radio navigation and localisation system enhanced by multiple satellites functioning from 12,000 miles up on the earth surface with ground stations that allows land, air, and seas users to determine their accurate locations, and velocity at all time and season globally (Lu, Chang and Liao, 2013; Hannan et al., 2015; Zurmotai, 2016; Milla and Lorenzo, 2005). The GPS systems are sub-structured into three systems: the space system made up of satellites, the control sub-system, the ground stations, and the users' sub-system (GPS users) (Hannan et al., 2015). In smart waste management, the use of GPS with other spatial ICT tools assists in tracking trash bins and trash collection vehicles "in observing location and collection time" (Hannan et al., 2015, 512). These IoT tools are also applied in monitoring waste processes from collection to disposal or recycling (Lee and Thomas, 2004).
- **RS:** Remote sensing is a technology that is used for data acquisition and classification from a remote/distant location enabled by aerial sensing (electromagnetic radiation) from airborne or satellites sensors, which is then processed into digital imagery (Hannan et al., 2015; Isah, 2015). Typically, these RS devices possess sensors, image processing tools, communication tools, all of which operates within a platform. The applicability of the RS technology in SWM is evident in Yang et al. (2008). The authors developed a system to analyse the leachate and gas emissions from landfills used for domestic waste disposal, in line with existing environmental regulations.

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Identification technologies for SWM system

Challenges involved in manual processes of waste management challenged scholars and waste management agencies to sort after technologies capable of automating and enhancing waste collection from bins (Gnoni et al., 2013; Hannan et al., 2015). The need for transition from manual methods of waste collection to a more efficient approach with the use of advanced technologies has brought about the applicability of identification technologies such as Radio Frequency Identification (RFID) and barcode in the waste management landscape (Lu, Chang and Liao, 2013; Hannan et al., 2015).

- **RFID:** Radio frequency identification is an automated data acquisition technology that uses frequency signals by sharing information between the transceiver and the transponder for object identification (Lu, et al., 2013; Hannan et al., 2015). This process is made possible by embedding a unique serial number of products on an RFID tag that can read and extract the attached serial number via scan (Hannan et al., 2015). As an enabling technology that has been used in various circumstances for object and people tracking, RFID supports the exchange of information in a dynamic form (Gnoni et al., 2013). In SWM, RFID has been used for various purposes such as bin tracking and monitoring (Chowdhury and Chowdhury, 2007), supervision of waste collection process, route optimisation, and sorting and recycling (Glouche et al., 2014).
- **Barcode:** This is an electronic device with the capacity of reading data embedded as codes and translates into information using an arrangement of geometric codes (Lu, Chang and Liao, 2013; Hannan et al., 2015). Ideally, a barcode is known as a combination of white and black lines, which provide an easy and affordable pattern of obtaining and recording information in various assets (Hannan et al., 2015). Barcode based SWMS is used to enhance intelligent recycling. This is done through source separation from waste generation process; collection and treatment through the provision of adequate 'dismantlement' data to recycling operators, which facilitate minimal landfill space, manage risk and promote advanced waste management (Saar et al., 2004; Stutz et al., 2004; Hannan et al., 2015).

Data acquisition technologies

The rapid development of technology-enabled data generation systems has since substituted the manual processes due to its enhanced functionality, effectiveness, cost efficiency, and minimal workforce required to perform specific tasks (Lu et al., 2013; Hannan et al., 2015). The application of technology-enabled data acquisition systems effectively tracks objects (Hannan et al., 2015).

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Their usage is essential where instant data collection is required (Faccio et al., 2011). These data acquisition technologies, as applicable to SWM, are sub-classified into sensors and imaging.

- **Sensors:** These are gadgets that can detect and measure real-world features. They extract physical attributes and compound properties and transform them into indicators directly detected or adopted by other devices (Lu et al., 2013). Essentially, a sensor is made up of two elements: the capacity to sense and the other with the ability to transduce (a device that converts variations such as brightness or pressures into an electrical signal) elements. The constituents can be applied in various circumstances, especially suited for online monitoring situations (Lu et al., 2013; Hannan et al., 2015).

  Various research has been conducted in various areas where sensors were developed and implemented in different areas of waste management. Such research includes 'sensorized' waste collection container for content estimation and collection optimisation (Vicentini et al., 2009), waste weight measurement status inside a trash bin (Chowdhury, 2007; Marques, 2014), and dynamic waste collection and pickup scheduling via remote access monitoring (Mcleod et al., 2013).
- **Imaging:** Imaging, also known as data image technology, is used in sensing activities, capture such an event, manipulate to make meaning and posts digital images, which can be in different forms such as camera, scanner, or video surveillance (Lu et al, 2013; Hannan et al., 2015). The applicability of imaging in smart waste management cuts across the cameras mounted to ascertain when a bin is filled and to what quantity (Arebey, et al., 2010); sense chip status from waste timbers (Konta and Ando, 2005 in Lu et al., 2013); and licence plate recognition used in SWM (Lu et al., 2013).

Data communication technologies

While technology evolves, the method of communication prevalent before the advent of the internet was mostly a manual process of data sharing (Hannan et al., 2015). Various channels such as the floppy disks, Compact Disc-Read only Memory (CD-ROMS), or local Supervisory Control and Data Acquisition (SCADA) systems were in use (Lu et al., 2013, 1602; Hannan et al., 2015). in comparison to the pre-internet era, three essential technologies are used to facilitate and communicate via the internet. These are copper wire, fibre optics, and wireless access (Hannan et al., 2015). Some communication technologies (Bluetooth, GSM/GPRS, VHFR, and GigBee) adopted for SWM are used either for long or short-range communication (Faccio et al., 2011; Lu et al., 2013; Hannan et al., 2015).

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- **Bluetooth**: This is a wireless radio system designed for short-range communication between peer-to-peer technologies which eliminate the need for cable for system peripherals such as mice, keyboard with the provision of low power consumption network (Lee et al., 2007; Hannan et al., 2015; Hashem et al., 2016).
- **Global system for mobile communication (GSM)/General packet radio services (GPRS)**: These are inter-related technologies as GSM is the primary technology that enables a 2G type of network which facilitates data transmission, while GPRS was an enhancement of GSM enabled internet services which fall under the category of long-range communication (Lu et al, 2013; Hannan et al., 2015). GSM network adopted for SWM is used for data transmission from the sensor to its localised server (Omar et al., 2016). Send notification messages to workers if the bin is filled and requires pickup (Wijaya et al., 2017).
- **Very high-frequency radio (VHFR)** is an ITU-8 designated communication technology with a 30-300 MHz bandwidth capacity, which covers a maximum distance of 10,000 m (Hannan et al., 2015). VHFR has been chiefly used in broadcasting (television and radio) corporations and long-range data communication (Seybold, 2005). Lee and Thomas (2004) proposed a high-frequency radio tracking system (Lee and Thomas, 2004) for usage in tracking the entire process of waste management from collection to recycling or disposal.
- **ZigBee**: This is a technology that enables minimal data consumption, low cost, minimal power usage and wireless network protocol "targetted toward automation and remote control applications" (Ergen, 2004, 2). Zigbee is built upon IEEE 802.15.4 standard, with characteristics of providing low power and low cost for wireless connectivity, defined by a physical layer and access control at a minimum rate (Howitt and Gutierrez, 2003; Ergen, 2004). While its known application cut across fields such as medical, agricultural, industrial and residential (Howitt and Gutierrez, 2003), its also been adopted as a short-range technology for solid waste monitoring and collection (Catania and Ventura, 2014; Longhi et al., 2012; Hannan et al., 2015).

2.3.2 Advantages of smart waste management

Waste collection in municipalities accounts for 10% to 25% of a city budget and poses the challenge of effective and efficient waste management (Minetti, 2020). According to the author, 15% of bins are generally over full, with different bags visibly placed around, thereby creating health and environmental hazards (Minetti, 2020). According to Minneti, smart waste benefits are enormous and should not be ignored by cities. These benefits include:

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- **Reduced cost**: To mitigate against indiscriminate waste disposal and bins overflow, cities increase the frequency of waste collection which inadvertently creates the possibility of emptying bins that are 40% full. Consequently, the cost of waste collection increases. SWM efficiency increases the cost of savings as trucks are dispatched when necessary and overall maintenance cost.
- **Improved quality of living**: Waste containers that are often used for waste collection are susceptible to vandalisation, heavy wind blow or kicked by humans and burnt, thereby creating safety risk, environmental hazards, as well as additional cost of purchasing new bins.
- **Increased security of waste bins:** While public waste, especially robbers, placed at various locations are susceptible to vandalisation, SWM, leveraging on IoT technologies, can generate an alert in the event of unauthorised movement of a bin, fire outbreak, or vandalism.
- **Improved quality of waste management:** With data generated and analysed, SWM can predict when the bin will need to be disposed of, thereby optimising the route for truck dispatch.
- **Waste-based energy production:** This is a process where waste is used to generate electricity via combustion (Aazam and Lung, 2016). This means the creation of an alternative source of power could be enhanced through the implementation of smart waste management.

While the importance of smart waste management can not be over emphasised, the introduction of the smart waste management system in Abuja can improve the quality of lives of residents (Amasuomo et al., 2015). Lending credence to the above assertion, Zamorano et al., (2009) holds that the optimisation of processes involved in waste collection can reduce recurrent cost and avert negative environmental impact.

2.3.3 Barriers to smart waste management implementation

In light of smart technologies' ubiquity and their general acceptance of their perceived effectiveness and efficiency in daily activities, smart waste management requires an innovative and well-followed vision to ensure a zero-waste city (Zhang et al., 2019). As promising as it may sound, there are specific barriers that could hinder the adoption of the SWM system, which includes but not limited to the following:

- **ICT infrastructure**: The ICT infrastructure of any system needs to be developed according to the smart cities' need and specificity (Gurani et al., 2019). For practical use, the system adopted can only perform well with appropriate infrastructure (Barbierato et al., 2019; Pasolini et al., 2019).

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- **Policy direction/strict regulation**: The absence of policy direction breeds insecure standards without a clear vision to guide implementation (Gurani et al., 2019). According to Hannan et al. (2015), IoT implementation requires a robust regulatory framework. Strict environmental policies and enforceable sanctions need to be in place to deter those who pollute and engage in improper waste disposal (Zhang et al., 2019). The absence of a proper regulatory framework is detrimental to the system (Moghadam et al., 2009).
- **Privacy and security**: While the SWM is geared toward networking with other technological systems, it is noteworthy that such a system is prone to malicious attacks, which may raise security and privacy concerns (Gurani et al., 2019). Achieving interoperability between the connected devices will require a conscious effort of maintaining and securing the privacies of the user of the systems (Gurani et al., 2019). Data security harms SWM implementation as there exists a tendency of making public households data (Schafer, 2014).
- **Transparency:** Operations shrouded in secrecy throughout the implementation of SWM, especially in purchasing required IoT facilities, tend to kill the idea on arrival (Gurani et al., 2019). Transparency is required at all stages of SWM implementation. It could isolate people with smart city knowledge while leaving room for less knowledgeable people (Evans et al., 2018).
- **Cost:** Upgrade in operations will require funding not just for the IoT implementation but also for high cost of professionals, devices and installation, routine maintenance, and training the field workers (Huang et al., 2019).
- **Connectivity and data availability:** With the objective of SWM technologies to provide instant data at every point in time (Gurani et al., 2019), this process may be marred due to unavailability or lack of data (Liono et al., 2018). Lack or poor network connectivity may pose SWM implementation (Sun et al., 2010 in Gurani et al., 2019).
- **Skilled personnel:** IoT implementation requires knowledgeable personnel from policy formulation to its implementation. City's administrators may not possess the organisational and technical skills needed for an effective waste management system (Talavera et al., 2017). Implementation of the policy also requires technical staff to provide a user-friendly and efficient system (Deore et al., 2019).
- **Turnover period:** Government is transient, and some businesses are focused on short term return on investment; hence their forecast primarily lies within a one to five years investment framework (Giunipero et al., 2012). Implementing smart technologies in waste management is capital intensive, but the effect may take years to be attained (Zhang et al., 2019). According to

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Zhang et al. (2019), it is a 'trade-off' between making profits in the short term or achieving a sustainable environment in the long run.

2.4 Conceptual framework

In this study, the conceptual framework of what constitutes a smart city by Nam and Pado (2011) was adopted. Several studies on smart waste management lay explicit emphasis on the use of technologies (Zhang et al., 2019; Hollands, 2015; Lu et al., 2013) without corresponding attention to other dimensions of smart cities. Nam and Pado (2011) categorised concepts of smart city into three factors: “technology (infrastructures of hardware and software), people (creativity, diversity, and education), and institution (governance and policy)" (Nam and Pado, 2011, 286).

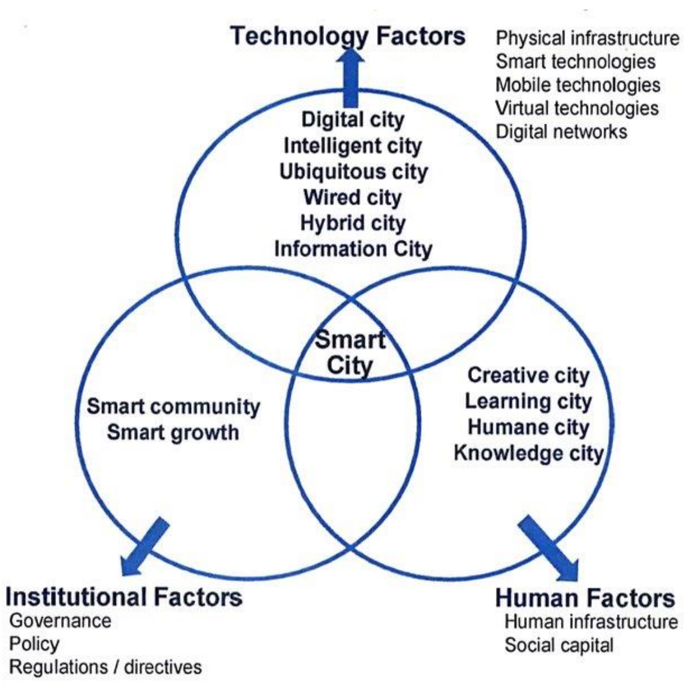

Figure 1. Fundamental components of smart city.
Source: Nam & Pardo (2011, 286).

The aspects of the framework are described as following:

Technology factors

The importance of technology in a smart city cannot be overemphasised. It utilises ICT in transforming processes in both professional and private living in a significant way (Hollands, 2008). A functional ICT infrastructure is essential in a smart city initiative but not enough in

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achieving the goal (Nam and Pado, 2011). Lindskog (2004) opine that "ICT infrastructure and applications are prerequisites but without real engagement and collaboration and cooperate between public institutions, private sector, voluntary organisations, schools and citizens there is no smart community" (Lindskog, 2004, 4). While the role of technology in smart city has been emphasised, Nilssen (2019) argued that technology is not the only defining feature of smart city initiative.

Institutional factors

Effective smart city initiative is governance dependent in its design and implementation and requires the full support of government and policy direction (Nam and Pado, 2011). According to the authors, this category requires policy direction and government role and intra and inter-agency collaboration. With the administration of smart city initiative constituted, there is the need for integrated and transparent governance, including marketing activities, forming clusters and promote collaboration. This is also the position of Klundert and Anschutz (2001), who argued that institutional factor is central to effective operationalisation of smart waste management system.

Human factors

This aspect is essential in making clear the essential factors but often neglected when conceiving smart initiatives. According to Nam and Pado (2011), the availability and quality of ICT technologies are essential but not the only requirement or characteristics of a smart city. Considering the place of human capital, human infrastructure and life long education in urban settlements and social inclusion in public services to all is essential (Nam and Pado, 2011). In the same light, effective and efficient systems are within the context of use with the direct involvement of citizens (Wilson et al., 2013).

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3. RESEARCH METHODOLOGY

This section provides detailed directions taken in the design and analysis of empirical findings. The methodology used for this study are broken down and discussed under four sub-headings. The first section focuses on the case design adopted for this study, aiming to justify the adoption of the specific research design method. The second part of this section provides a detailed overview of data collection procedures. The third phase gives procedures on how the generated data was analysed. The last section focuses on the validity and reliability procedure used in this study and summary.

3.1 Case study design

This study adopts a case study methodology, as it seems to be of relevance to the context of this research. According to Karlsson (2016), the central features of a case study is the intensity of its investigation of a real-life situation. In the same vein, Yin (2018) defines a case study as an approach used to generate an in-depth understanding of a complex issue in its real-life context. A case study is unique because its method is determined by the research that utilises occurrences and everyday people as data sources within the scope of the research (Hyett et al., 2014). Various authors (Callejo Gallego et al., 2004; Sandelowski, 2011) have diverse understanding of what a case study stands for. However, according to (Crowe, 2011), critical elements to these varied definitions are that it is a thorough or 'in-depth' exposition of a phenomenon not in abstract form but ‘a real-life situation’. By implication, a case study is an ideal methodology for knowing about waste management practices as applicable in Abuja.

In choosing a case, one must consider the purpose of the study before deciding either a single or multiple case studies. However, the context of defining single and multiple cases has raised debate over time. According to Gerring (2004), a case study entails an "intensive study of a single unit to generalise across a larger set of units." (Gerring, 2004, 341). According to the author, what is constituted as a single case study is not a single case in the general sense because units can be generated in-between, bringing about multiple cases. In the context of this research, a single case study is understood to mean the study of the phenomena of interest by analysing a specific area of interest. Rather than focus on a larger sample, Yin (2018) argued that if the purpose of a study is

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to understand a specific phenomenon, a single case study is ideal, and as such, this study adopts a single case study.

3.2 Data collection procedure

Data collection procedure entails a systematic approach employed through which data used in making a conclusion is generated and used. Data collection is the dynamic process of extracting accurate information without losing its meaning, thereby maintaining the credibility of its analysis for informed decision making (Sapsford and Jupp, 2006). For credibility as well as ensuring the validity of the result of this finding, data triangulation was adopted. Data triangulation has been viewed as a strategy in qualitative research to test validity through multiple sources of data for data (Carter et al., 2014). This research relied on secondary (document analysis) and primary (interview) data sources through semi-structured interviews. An interview is the best approach in data collection perceived as talking, and talking is natural (Hofisi, Hofisi and Mago, 2014), mostly used in qualitative research (Griffee, 2005).

3.2.1 Document analysis

As an analytical method in qualitative research, document analysis entails a methodical approach for assessing or evaluating both printed and non-printed documents (Bowen, 2009). Evaluating literature provides an in-depth understanding of the research area with a major objective of enabling the author to make an informed deduction about the phenomena under review. Central to materials evaluation in qualitative research is thorough examination and interpretation of documents. The purpose of the examination is to make meaning and postulation, which are added to scholarly knowledge (Bowen, 2009; Corbin and Strauss, 2008). The Abuja master plan and executive report of the document were analysed in this study.

In the present study, the first step used in literature selection was carried out by defining the criteria, identified keywords, and field of research, knowing fully well the diversity inherent in the content of a smart city and its initiatives, which informed appropriate sources of materials. Secondary data search was done in the web of science, Scopus, research gate, journal of urban planning and development (ASCE), google scholar, reports and academia (Tranfield et al., 2003).

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3.2.2 Interviews

Interview represents the primary source of data collection for this study. An interview "records and analyse people's opinions, experiences, beliefs and ideas on relevant topics" (Parveen and Showkat, 2017, 4). According to the authors, this process of data collection presents the interviewees with an opportunity to be more detailed with their response, thereby creating a deeper understanding of the phenomenon under review as against other data collection techniques such as questionnaires and survey. In addition, Gill et al. (2008) assert that interviews are appropriate tools to deploy when dealing with sensitive topics better explored in a closed group than an open group. Exploring the phenomenon under review, this study undertook semi-structured interviews with residents and administrators within the scope of the study. To get a deeper understanding, the author relied on the research questions and objectives and developed a set of 'guided' questions which were open-ended, aimed at giving the interviewees the avenue to share their thoughts and knowledge of the subject under review without external factors (such as browsing the web to provide a response) which could influence their responses. Semi-structured interview questions keep the author focus on the line of conversation, being guided by a set of predefined questions (Bell et al., 2012). (see Appendix 3 for interview recordings).

The steps adopted in constructing the semi-structured interviews were the five stages of developing a semi-structured interview guide proposed by Kallio et al.(2016). The five stages, according to the authors, include (1) identifying the prerequisites for using a semi-structured interview; (2) accessing and using previous research; (3) formulating preliminary interview guide; (4) pilot testing the proposed guide; and (5) presenting the complete semi-structured interview guide. The five stages are discussed in the following sequence:

1. **Identifying the prerequisites for using a semi-structured interview:** The first phase in this process was aimed at evaluating the appropriateness of using a semi-structured interview for a rigorous data collection process with the research questions (Kallio et al., 2016). This process entailed the author's previous knowledge and the phenomenon of the research study (Turner, 2010). Semi-structured interview is ideal when the author wants to test the participants level of awareness of the subject matter and give room for opinions to be expressed (Cridland et al., 2014).
2. **Assessing and using previous research:** This phase holds that gaining access to previous studies would grant the author adequate knowledge and identify the need for complementary

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empirical work (Turner, 2010; Kallio et al., 2016). This is conducted through an extensive review of previous literature about the subject matter (Krauss et al., 2009).

3. **Formulating preliminary interview guide:** The interview guide is a list of questions (Krauss et al., 2009), which are formulated as a tool for data collection with the aid of previous knowledge (Krauss et al., 2009; Kallio et al., 2016).
4. **Pilot testing the proposed guide:** After a preliminary question has been formulated, the fourth stage requires the author to confirm the coverage and relevance of the formulated questions via a pilot test (Kallio et al., 2016). This is meant to ascertain the need for a review of the contents of the guide and improve quality (Chenail, 2011).
5. **Presenting the complete semi-structured interview guide:** The goal of this last phase of the development process is to come up with a clear and logically structured semi interview guide capable of answering the research questions (Kallio et al., 2016). (See appendix 1).

List of interviewees

Interviewees from the management side included one (1) Deputy Director at the Abuja Environmental Protection Board, One (1) site officer at Development Control (DC). Others included: two (2) residents of the Abuja phase 1, which has undergone complete development; two (2) residents of phase 2, which has undergone partial completion and both of whom are public servants of senior management level; two (2) residents of phase 3 which is still experiencing development and one of whom is an editor of a national newspaper and the other a system engineer in the public sector; none from phase 4 as development work is underway but occupied by squatters. To maintain participants' privacy, the author assigned codes to everyone, annotated as 'interviewees identifier'. See Appendix 2 for list of interviewees with codes used when expressing the opinions of individual participants.

Since the Abuja master plan made provision for satellite towns with the Satellite Towns Development Department and the Area Councils overseeing its waste management, this research extended to capture the views of residents in these locations as well as the prevailing practices. The author identified and interviewed residents of three adjourning satellite towns with proximity to the FCC. This diverse pool of interviewees was informed by the need to have a holistic view of practices and challenges as an accurate representation of the FCT to advance a solution.

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3.3 Data processing

This section x-rays the methods employed in the analysis of the acquired data to translate into meaningful information. Based on the nature of the finding and the phenomena under review, the author transcribed the data from audio into a word document to make meaning of it with the aid a software known as 'otter.ai'. The analysis was carried out with the aid of a Research Question Data Analysis (RQDA) software shortly after the data was collected, to ascertain the need for additional data collection if the responses were not sufficient to arrive at a conclusion. This study adopted Braun and Clarke in Maguire and Delahunt (2017) six-phase framework for doing analysis, which are:

1. Familiarise oneself with the data,
2. Generate initial codes,
3. Search for themes,
4. Review themes,
5. Define themes,
6. Write-up.

While these phases could be carried out in sequential order, the authors argued that the steps are not linear, and as such, one may move forward and backwards as many times as possible. Every repetitive and relevant repetition observed during the interview where noted. Codes were generated based on the relevant information after the author got acquainted with the data. In the third stage of the analysis, the author selected and categorised responses with similar patterns. The next step involved in this process was to review these categorised codes and patterns, review, and grouping while ensuring there were relevant to the research objective. The result of the processes was then generated, making an informed presentation of the phenomena under review. (see Appendix 4 for interviews transcripts).

3.4 Validity and reliability procedure

Validity is the extent to which the test instrument measures what it was meant to measure (Bordeianu and Morosan, 2013). Various types of validity used include content validity, criteria and factors validity, and construct validity. For this research, construct validity was relied upon for most of the data collected in this study. According to Bordeianu and Morosan (2013), construct validity is most often applied to instruments that measure knowledge. This research aims to create a point of convergence between the author and the interviewees to achieve the objective of the

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interview. In reliability, the outcome of any research is essential as it affects decisions taken at any level. As such, the reliability of the data is sacrosanct. The general understanding of reliability is that whoever wishes to replicate particular research questions and achieve the same results, the steps adopted for the initial research are followed to the latter (Yin 2018).

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4. RESULTS

This chapter presents a thorough description of the case selected through analysis of data collected (4.1). Also, this section provides insights into the analysis done using Research Question Data Analysis (RQDA) which is an open-source computer-assisted qualitative data analysis tool (Chandra and Shang, 2016). The results of the findings are explained in 4.2 as a) provisions for waste management in the Abuja master plan, b) existing waste management practices in the Federal Capital Territory (FCT), c) factors that could hinder the adoption of SWM within the FCT, and d) stakeholders involved in the eco-system and their roles.

4.1 Case description

Before the emergence of Abuja as Nigeria's capital city, Lagos was the nation's capital. Its choice was premised on essential advantages inherent at the time. Central to Lagos edge was: its trading hub with accessible communication with Europe and its rail infrastructure, which enhanced communication with other parts of the country; and availability of basic infrastructure such as electricity supply (Bons et al., 2018). At the same time, there were concerns about Lagos being the nation's capital, the creation of states in 1967 that made Lagos a state and then Federal Capital Territory. According to Bons et al. (2018), the administration of what was then known as the Federal Territory came directly under the new state (Lagos) government. With conflicting roles of both governments being carried out within the same territory, the role of Lagos to play dual-purpose gradually diminished, thereby increasing the call for a separation of territories.

The desire for a new capital was premised "on the increasingly diminishing capability of the Lagos territory to cope with the strong expansion of socio-economic activity which accompanied the oil boom of the 1970s, and the unavoidable increase in demand for greater efficiency in administration of the country" (Bons et al., 2018, 1123). As a result of overwhelming demand within the Lagos territory, saw physical resources, urban infrastructure, and land space became insufficient to sustain the status of Lagos. The dual role of Lagos with ever increasing infrastructural deficit, made its continued use unthinkable within the administrative and political realm (Bons et. al 2018). According to the author, Lagos was becoming unliveable, unserviceable, and ungovernable.

In response to the yearnings for a desirable Federal capital that is geographically secure with adequate land and natural resources needed for urban development, the then military regime of

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late Murtala Mohammed constituted a panel in 1975 (Ikoku, 2009; Bons et al., 2018). According to the authors, the panel terms of reference included: Assessing the issues in contention and advise on the desirability to retain or relocate the federal capital; advise on a possible alternative if the federal capital was to be relocated, taking into consideration, its accessibility to other parts of the country.

Justice Akinola Aguda led panel recommended the relocation of the Federal Capital from Lagos to Abuja, a virgin land with a land space of about 8,000 sq. km, while the original settlers were to be resettled in nearby states (Ikoku, 2009; Wapwera, 2015). According to the authors, the choice of Abuja was informed by its centrality and ethnic neutrality. Abuja is bounded by Kaduna, Kogi, Niger, and Nasarawa states. In 1976, the new Federal capital was borne and gazetted in the FCT Decree number 6 (Wapwera, 2015). Figure 2 shows the location of Abuja at the centre of the map of Nigeria.

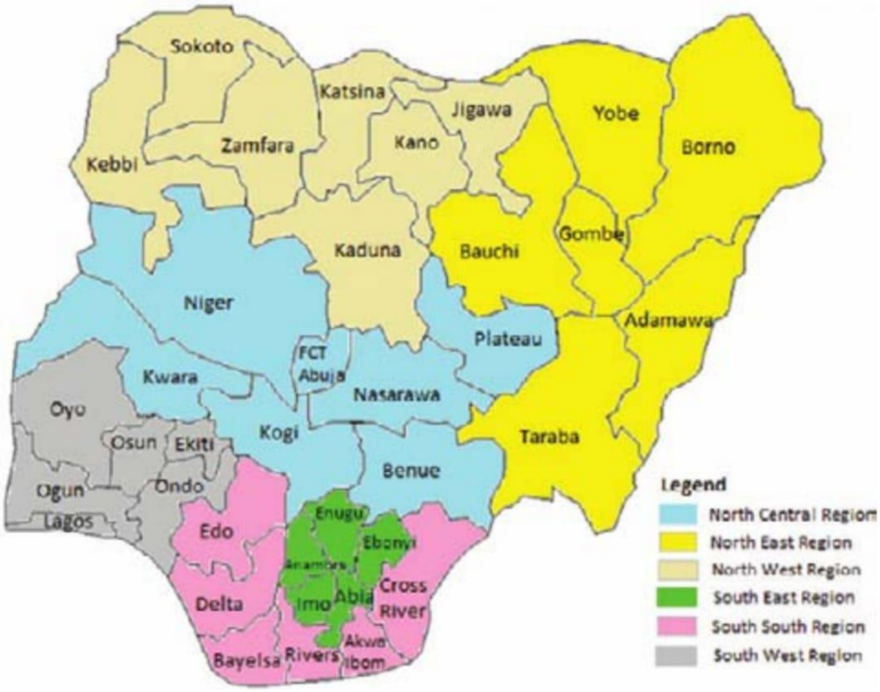

Figure 2. Map of Nigeria
Source: CIA in Japan International Cooperation Agency (2019).

The law backing the creation of the new FCT with an administrative body known as the Federal Capital Territory Administration (FCTA) also provided for the establishment of the Federal Capital Development Authority (FCDA), saddled with the mandate of planning, designing, and developing the new city (Ikoku, 2009). After thorough research on various models to create a master plan for the FCT, the Federal Capital Development Authority (FCDA), through an

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international bidding competition, commissioned a consortium of architects' urban planners and engineers under the umbrella of International Planning Associates (IPA), a United States-based consortium in 1977. The report of IPA in 1979 gave birth to the AMP, which was refined by urban design teams, and its final report was submitted in 1983. The final copy of the AMP, in which implementation has been a subject of discussion till date (2009). Figure 3 shows the developmental phases of the Abuja master plan of the Federal Capital City (FCC).

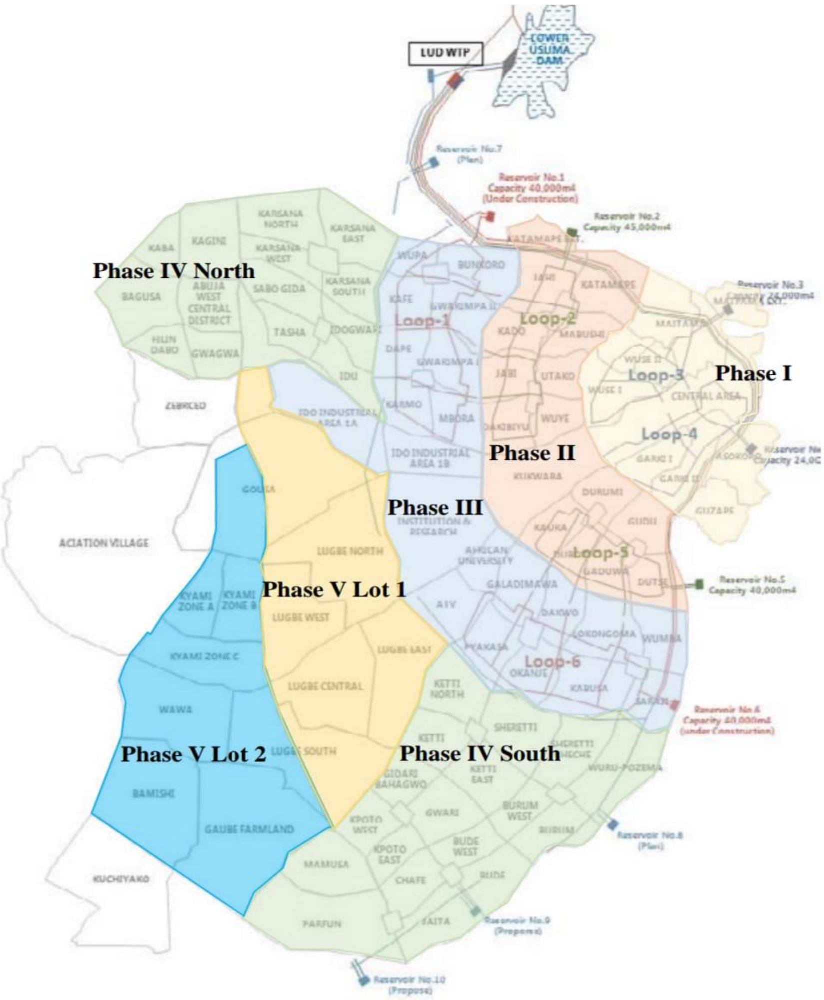

Figure 3. FCC Development Phase and Plan Pipelines
Source: FCDA and JICA (2019).

Abuja was designed in 4 phases with various cadastral unique identifiers, including districts and neighbourhood centres. According to G02 (2021), the AMP was reviewed with an additional area, originally under the Abuja Municipal Area Council, marked as phase five (see figure 3). Lands belonging to phases 1, 2, 3, 4, and 5 are coded with prefix A0, B0, C0, D0, and E0, respectively. Phase 1, which is the city centre is the most developed area in Abuja. Notable places within phase 1 include the central business district, which houses places such as cooperate headquarters of both

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public and private practices, the three-arm zone (Presidential villa, National Assembly complex, and Judiciary headquarter), Defence headquarters, police headquarter, and highbrow residential areas. Phase 2 is the second most developed area while still under construction with suburbs and a couple of squatter settlements. Phase 3 is next with many private estates with a greater number of squatter settlements and suburbs. Phase 4 is yet to be developed but occupied by squatter settlements. Phase 5, being the new addition to the FCC, is the popular axis known as Lugbe. Each phase has several districts which are meant to contain most of the things required to sustain households. From the AMP (currently applicable in developed phases), each district is equipped with facilities such as police stations, postal offices, hospitals, big shopping malls, fire service stations, and district parks. Districts have subsets known as the neighbourhood centre. According to Adeponle (2013), neighbourhood centres are designed to contain about five thousand people with facilities to meet every day's demand of its residents.

The master plan conceptualised an integrated and sustainable city according to Adeponle (2013), the plan was designed to create a framework for orderly planning of the FCC, and it adjourns centres. According to Ango in Adeponle (2013, 148), strict adherence to the provisions of the AMP would guarantee a modern city, devoid of "pollution, traffic jam, congestion, filth, dirt, diseases, delinquency, and all the other things that make life miserable, unhealthy and hazardous for people" (Adeponle, 2013, 148). Figure 4 shows the Map of the Abuja Federal Capital City with the red dots indicating squatters' settlements.

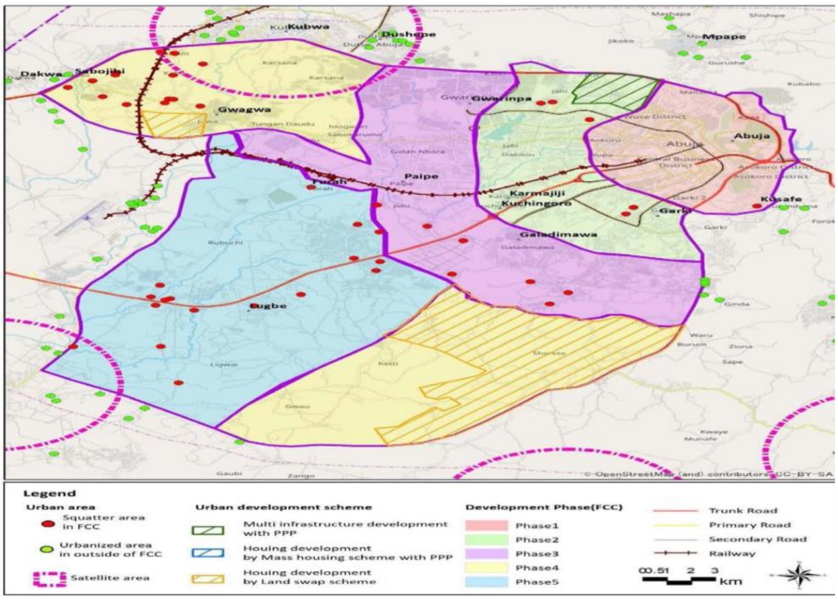

Figure 4. Squatter settlements in the FCC.
Source: JICA (2019).

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From the figure above, within the planned areas of the FCC, several squatters' settlements (identified in red dots) emerge in virtually all the phases, thereby straining the capacity of planned infrastructure. The results of the waste generation survey carried out in the FCT in 2015 indicate an increase in yearly waste generation within the planned area of the AMP (FCC) and the satellite towns (ST) in the six area councils the ST. According to JICA (2019), the quantity of waste generation predicted in 2018 within the FCC is 1,914 tons/day and 1,245 tons/day in the Area councils (AC). Figure 5 shows the amount of waste generated within the FCT.

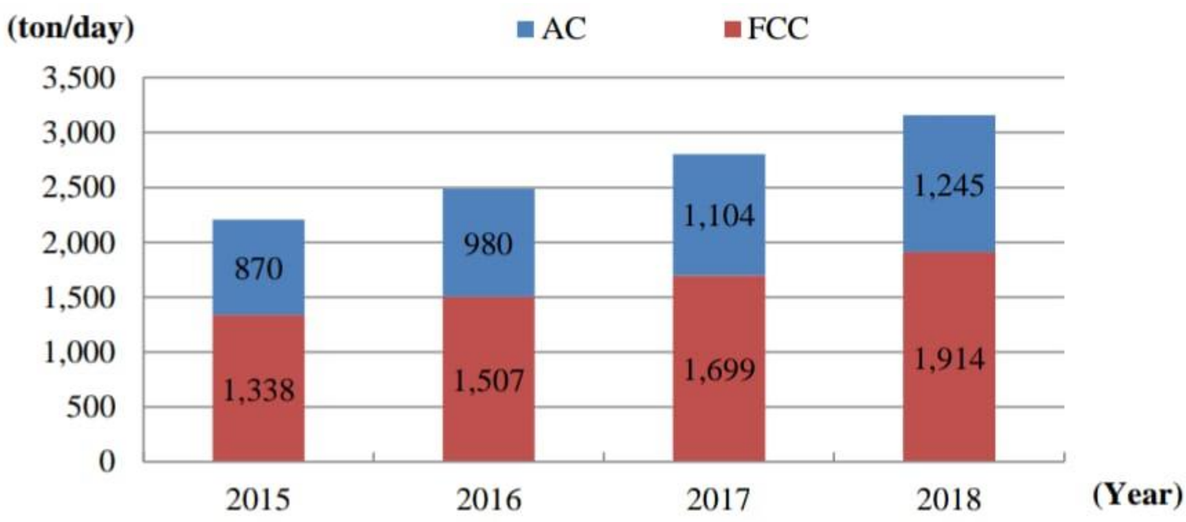

Figure 5. Amount of FCT waste generation prediction
Source: AEPB in JICA (2019)

From the report of the Japan International Cooperation Agency (2019), the FCTA, through its implementing agency, the Satellite Towns Development Department (STDD), is saddled with developing satellite towns and providing adequate infrastructure, including solid waste management in these related towns. The Abuja Environmental Protection Board (AEPB) is responsible for the operations and maintenance of sewage facilities, grant approvals for septic tanks installation, and provide technical direction to users of the tank and solid waste management. The AMP made provision for infrastructure design of solid waste management. According to JICA (2019), solid waste management is implemented through the Public Private Partnership initiative with detailed plans for its maintenance. Solid waste management system in Abuja has faced a series of challenges that are evident in improper waste disposal, especially common around squatters' settlements and satellite towns. From the recommendation of JICA, the AMP has not undergone a comprehensive review since its adoption. This is especially required to enhance its

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infrastructure provisions across all sectors such as transport, power supply, land use plans, and waste management through collaboration with the private sector. The current state of waste practice necessitates the need for an integrated waste management system that could be enhanced by adopting technology in the management processes.

4.2 Findings

This section is devoted to describing and examining the findings generated by analysing the data collected in this research. As earlier mentioned, data was generated in two-fold, document analysis and a semi-structured interview with residents and administrators of the Abuja waste management system. To gain a deeper knowledge of the background of the interviewees, the first category of questions (appendix 1) was framed to assess the validity of their responses, while the subsequent sections were aimed at extracting responses geared toward achieving the research objectives. The results as categorised are discussed as follows:

- Provision for waste management in the AMP
- Existing waste management practices in the FCT
- Factors that could hinder the adoption of SWM within the FCT
- Stakeholders involved in the eco-system and their roles.

4.2.1 Provision for waste management in the Abuja master plan

Abuja, also known as the FCT was a creation specifically with a detailed document that was developed to guide the planning and development of the city. To answer the research question ‘What is the provision of solid waste management in the Abuja Master Plan (AMP)?’, the research relied on documents review and interviews.

From documents analysed, there were pointers that the AMP made provision for waste management without an in-depth process. Due to limited resources, the provisions of the AMP could be summarised as follows:

- Waste collection and disposal is conceptualised in the AMP.
- The AMP identifies two locations for waste disposals which are Gaube and Gosa landfills.

Most interviewees (residents) believed that the AMP made provision for waste management. However, its effectiveness is what they were not sure about. Reports from residents indicated that none of them has access to the AMP but are aware it exists. Also, the various practices of waste management cast doubt on the effective implementation (if any) of a detailed plan. Interviewee

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A02 believed that it would only be reactional to assume that there exists a plan for waste management in the AMP. According to A02, "Like I mentioned before, I know there's a master plan. And I've not, I don't, I'm not privy or maybe I've not gone looking for it. Well as it is now, I guess, for every master plan is supposed to be plan for disposal of waste. If it's being carried out as planned, I don't know. I'm not too sure.”

Representing the city's administrators view, interviewee G01 was asked about the Board's mandate and provisions of waste management in the AMP. According to interviewee G01, the Abuja Environmental Protection Board is mandated to ensure and maintain a clean and suitable environment toward ensuring the wellbeing of all residents of Abuja. Responding to the two landfills identified from the document analysis, interviewee G01 believe that the landfills are only in principle but not in practice. According to G01, "Talking about landfill that you see, we don't have sanitary landfill in Abuja, what we have in Abuja dumpsite. For now, the sanitary landfill as captured in the master plan, non is functional. We cannot say we have it when it's not functional, and you can only have it when its functional."

Further inquiry on available literature and reports on the above subject matter revealed that the AMP's assumption not making adequate provision for waste management was something to hold on to. A panel constituted with the mandate of developing a detailed road map for solid waste management in 2016. Generally, various initiatives under the national policies have been proposed toward improving waste management. These policies include: the National Development policy 2017 – 2020 with a focus on developing an environmentally conscious ethical solid waste management system (JICA, 2019); The National Environmental regulation of 2009 geared toward creating a regulatory framework for adoption of sustainable and eco-friendly practices in waste management; The National environmental sanitation policy of 2005 was geared toward ensuring a healthy and hygienic environment to improve quality of life and ensure sustainable living; and the National Policy on solid waste management in 2018 toward harnessing waste as resources for economic growth and promote an eco-friendly environment.

This finding is in line with the institutional factors of smart city as contained the conceptual framework. According to Nam and Pardo (2011), for a smart city initiative to be effective, the support of government and policy direction for smart city design and implementation is fundamental. According to the authors, unwavering support from the government, and a functional administrative system is expedient for effective implementation of a smart city initiative.

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4.2.2 Existing waste management practices in Abuja

It is pertinent to study and review the existing system and practices if the objective is to advance a practical approach. Therefore, to answer the research question 'what are the current practices of urban waste management in the FCT?', interviewees were interviewed to get some knowledge related to their area of residents.

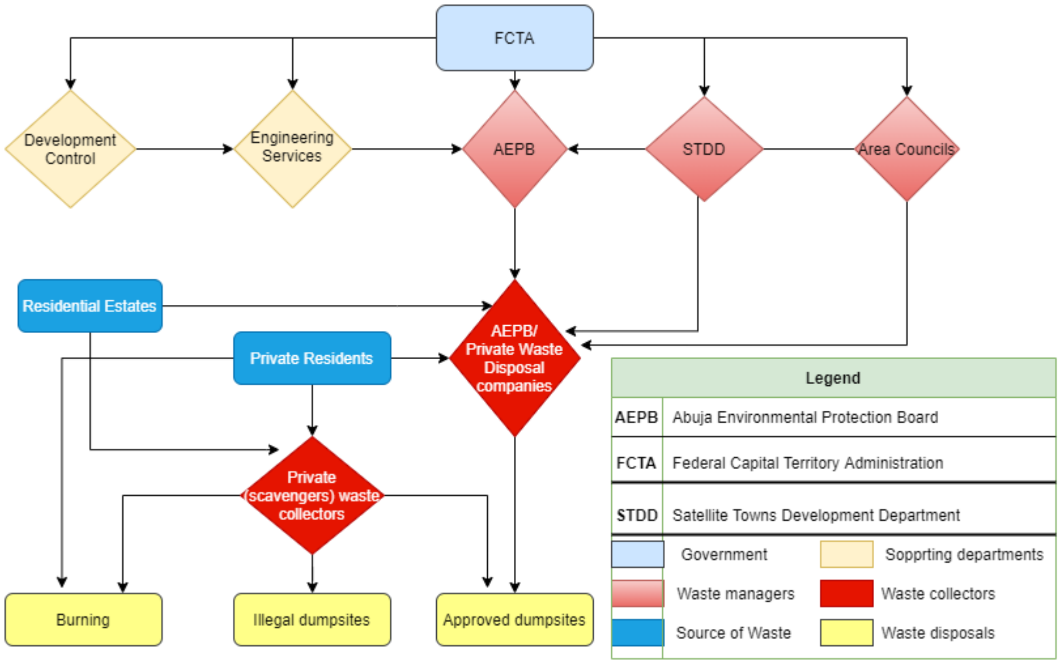

Figure 6. Abuja Waste Management Flow
Source: The author

The administration of the FCT is the responsibility of the Federal Capital Territory Administration (FCTA) headed by a minister who reports to the national assembly. The FCTA has various organs, and those relating to waste management are: Development control sees to proper land use; Department of Engineering Services provides waste disposal infrastructures; Abuja Environmental Protection Board (AEPB) is responsible for the sanitary of the FCC specifically with some level of oversights at the Area councils which houses areas out of the FCC; the Satellite Town Development Department (STDD) and the Area Councils are primarily responsible for waste management within the satellite towns. While the AEPB is also directly involved in waste collection, G01 reported that the organisation also issues licences to private waste collectors.

Following figure 6, solid waste is generated from both private and estate residents. However, waste collection and disposal are carried out by the approved agencies, privately licenced waste collection agency, un-official waste collectors (scavengers) and the residents as well. Residents of the FCC report that, waste generated from their homes are usually put in waste bags and taken to designated waste bin which are typically located just outside their residence. According to these interviewees, the disposed wastes are regularly collected by the agents of the AEPB in time with fewer cases of waste overflow.

Further inquiry into practices of waste management within the FCC revealed similarities in the processes. According to interviewee A02, waste collectors pick up waste twice a week while residents generally pay utility bills; hence there is an effective waste management system. Adding to the assertion of interviewee A02, A03 believed that there is a good waste management system currently in place within the FCC due to how regular these wastes are collected and disposed. Additionally, interviewee A03 reported that the fact that monthly utilities for waste collection are always charged signified the involvement of the Government.

Respondents who reside within the suburb axis of the FCC gave a different account on waste management practices which were somewhat similar. According to interviewee B02 who resides in a suburb of phase 2, every household is responsible for waste disposal. As such, every household engages private individuals for regular waste collection, but where and how the waste is disposed of is unknown to this resident. The practice reported by B02 is similar to what is prevalent in two separate satellites towns as reported by ST3 and ST4.

Interviewees C01, C02, E01, and ST1 from phase 3 and satellite town reported almost similar practices. According to these interviewees, through its management, the estate residents' contracts private waste collection companies that collect waste once a week. Any household that fails to pay for utility fees, such waste generated from that home will not be collected for disposal. The frequency of waste collection varies from twice per week to once a month. According to this category of interviewees, this practice's major challenge is renegation on the part of the waste management administrators and the absence of a unified process within the FCT. A resident within the satellite town revealed that waste generated from his home is not being collected but beholds the household to dispose of, usually burnt at the back of their home. According to interviewees ST3 and ST4, waste generated are not collected through officials of the administrators nor its agents but are privately collected and paid for.

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The common ground among all residents who took part in this research was that they never separate their waste. All waste generated are usually lumped into one trash bag. What happens to the waste collected is unknown to them. However, most of the interviewees were knowledgeable about the existence of landfills in the FCT. Only one resident in the ST knew about the existence of a recycling centre privately owned. In all of these approaches to waste generation and collection, only residents of phase 1 and phase 2 within the city centre were very comfortable with the current waste collection model. The number one challenge administrators face, which has been severally emphasised within the current practice, is supervision. According to G01, lots of staff are required for a complete oversight function on the duties of the private licenced waste collectors and the resident's compliance to laid down approach towards waste generation and disposals. Figure 7 indicates the dumpsites locations within the FCT.

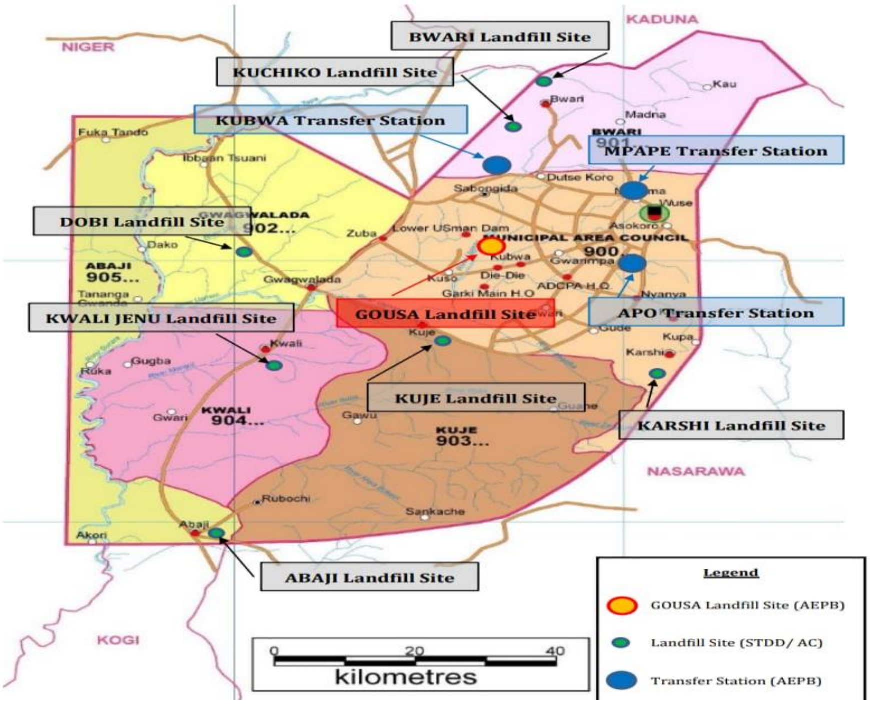

Figure 7. Abuja solid waste treatment facilities

Source: JICA (2019)

Waste collected by relevant bodies were meant to be taken to any of the three transfer stations, undergo combustion and the ashes taken to dumpsites. While transfer stations are not functional, waste is taken directly to the landfills without treatment. From the Japanese International Cooperation Agency report, the AMP captured two landfills (GOSA and GAUBE). However, the current state of waste management in the FCT shows that only one of the original locations is in use (Gosa). According to interviewee G01, this location serves as a dumping ground and nothing

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more. However, G01 reported that two transfer stations meant for waste treatments are under construction. Other waste dumpsites managed by the STDD and AC are reported to be open dumps without a controlled environment (JICA, 2019). see figure 7.

4.2.3 Factors that could hinder the adoption of smart waste management

This category was crafted to consider the views of residents and administrators of possible setbacks that might affect the adoption of a new approach to waste management. In the interview, respondents were asked about possible factors they felt could hinder the full adoption of smart waste management and how these challenges could be handled. Such areas, according to interviewees, includes funding, lack of maintenance culture, technophobia, inadequate infrastructure (network, road, electricity), political will, political landscape, right personnel, lack of strict regulatory enforcement and non-inclusion of residents in the design and implementation processes. These factors are presented and discussed as follows:

- Residents and waste administrators who took part in this interview were unequivocal about funding being a significant source of setback to full implementation of smart waste management. They emphasised that appropriate funding was a panacea for the effective implementation of SWMS. Most interviewees believed that funding of this project should come from the part of the Government. However, interviewee ST3 believed that the private sector should fund the initiative, or at most, through a public-private partnership.
- Four interviewees mentioned lack or poor maintenance culture as another challenge for the adoption of smart waste management. According to interviewee ST1, while it is easy to install the necessary technologies, sustainability will be an issue due to poor maintenance culture inherent in some government projects in Nigeria.
- Technophobia was also identified as another possible setback. According to interviewees C01, though SWM is a lofty and appealing project, many people are resistant to change, especially in technology adoption and prefer to maintain the status quo.
- Inadequate infrastructure received great attention from both the city administrators on waste management and residents as a possible major setback. According to interviewees G01 from the administrators' point of view, a good road network is required to access dumpsites. Inadequate internet coverage and lack of steady electricity to power the IoTs would be an issue to be dealt with, according to interviewee ST3.
- Political will power was identified as a significant challenge as well as a solution. According to interviewees, where there is a political will, every other huddle can be surmounted. This

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assertion by the residents was collaborated by the administrators. According to G01, political will power is the number challenge.

- The political landscape was identified as another challenge. According to interviewees, projects or initiatives are hardly continued by successive Government as every new leader would want to start his or her own project, thereby abandoning that which a predecessor started. Lending credence to this assertion, interviewee ST4 agreed that most of the problem faced in Nigeria is because of lack of consistency.
- Right/skilled personnel was also mentioned as a possible challenge. According to interviewees, the Nigerian Government is known to use square pecks in round holes because of sentiments and emotions. Often, this is driven by greed, which accounts for many abandoned projects.
- Lack of strict regulatory enforcement was one of the issues raised by interviewees. According to interviewees, there is a need for a detailed regulatory framework and made public the provisions of the law and residents' obligations. While this was generally acknowledged as central for effective take-off, interviewees argue that the law must go beyond enactment to full implementation with stipulated and enforceable sanctions.

Interviewees, both residents and administrators, affirmed the need for awareness creation while conceptualising the new approach. According to interviewees, there are chances that technologies alone cannot guarantee the effectiveness of the proposed new approach with notable circumstances like network downtime and residents' compliance. Relying more on residents should be considered right from conception to full implementation. Giving ownership of such project to residents has a greater chance of gaining the support of the people.

From the technological factor of smart city initiative, Hollands (2008) asserts that technologies are central to the efficiency of smart city. Similarly, Nam and Pardo (2011) align that a well functional facilities are necessary but will depend on other factors to make a city smart. The findings of the research question on possible factors which could impede SWMS implementation aligns with the proposition that, ICT infrastructure are needed in smart city initiatives as well as the collaborations with other sectors including the citizens (Nam and Pardo, 2011).

4.2.4 Stakeholders involved in waste management eco-system and their roles

This section was crafted to identify the stakeholders involved and their roles in the prevailing waste management practice in the FCT. To answer the research question ’how can the implementation

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of smart waste management initiative influence the action of stakeholders in the eco-system?', the author sort to find out the influence of the current waste management practice on the roles of stakeholders. To better understand the stakeholders and their roles, the views of both waste management administrators and residents were considered and summarised as follows:

- The Abuja Environmental Protection Board (AEPB): Responsible for solid waste management and enforcement within the FCC, grant approvals to private waste collection companies, sales of waste bins to residents within the FCC, door-to-door waste collection, market and illegally dumped waste collection, management of approved dumpsites, owns and deploy waste collection vehicles.
- Department of Development Control: Land allocation and inspection.
- Department of Engineering Services: Planning and designing waste management systems, supervision of solid waste treatment facilities, grant approvals to building construction engineers on proper disposal of construction waste.
- Satellite Towns Development Department (STDD): Responsible for providing amenities in satellite town, responsible for waste management in the satellite town, own landfills separate from the ones identified in the Abuja master plan.
- Area Councils (AC): responsible for waste management in satellite towns within their jurisdictions, co-ownership of dumpsites with the STDD.
- Private waste collection companies: responsible for solid waste collection and disposal in the Federal Capital Territory.
- Residents: Generate waste, have a responsibility to ensure appropriate waste disposals, pay waste collection fees for those residing where there are appropriate waste disposal measures, and comply with the directives of waste administrators.
- Media: creating awareness on proper waste management and constantly reminding the public of their obligations.

Interviewees revealed their genuine interests and were significant in handling the research objective. Existing in a world with general issues as well as issues peculiar to certain locations, some of the issues raised confirmed existing findings while others were new information that provided insight for this research. Technology plays an important part in smart waste management system however, human infrastructure and affinity to lifelong learning is also germane (Nam and Pardo, 2011). A smart city as a multi-stakeholder eco-system promotes the co-creation value of collaboration between various actors to deliver the anticipated importance of the smart initiative (Mayangasari, L., and Novani, S., 2015).

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5. SMART WASTE MANAGEMENT FRAMEWORK

This section is dedicated to summarising the findings of this research and suggest the framework for the adoption of smart waste management system in Abuja. In the previous chapter, the author sought to lay the views of interviewees based on specific interview questions guided by the research questions (Appendix 1). This section summarises these various views and make recommendations based on the findings. In addition, it provides a framework for the adoption of smart waste management system.

5.1 Discussion

With the focus of this research on having a greater understanding of the provisions of the AMP and the prevailing waste management practices in Abuja, the results of this research showed conformity to the conceptual framework adopted for this work (see Figure 1). The findings of the research conform to the three factors of smart city initiatives as contained in the conceptual framework: technological, institutional, and human factors. This research finding revealed that as planned as Abuja is, there are various practices of waste management (e.g., collection by assigned agents, private individuals known as scavengers, and individuals who burn their waste) with no functional treatment plant (see Figure 6). The FCC, which is a jurisdiction of the AEPB has no full coverage of waste management except the city centre, and the effective model prevalent within the city could be attributed to the fact that the area houses essential public and private organisations. However, with the effectiveness within the nucleus of the FCC, waste administrators encounter challenges. These challenges include monitory for compliance from both households and private licenced waste collectors, inadequate funding and staffing, the bureaucracy that characterises the administration of the FCT and lack of political will. Also, most areas where waste is burnt are within the jurisdiction of the Area Councils where open dump is practised. Additionally, administrators of waste management in the FCT believe that smart waste management would make their job more efficient.

5.2 Recommendation

To tackle the challenges identified in this study, the author proposed a set of recommendations. With the main objective of this research in mind, these recommendations are amplified and developed into a framework that could guide the adoption and implementation of smart waste management system. The recommendations which serve as the core of the framework for the

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adoption and effective implementation of SWM were created based on the literature review on smart city initiatives, and smart waste management. The recommendations are presented and discussed as follows:

1. Management collaboration
2. Policy framework
3. Regulatory enforcement
4. Open governance
5. User-centricity
6. Technology adoption
7. Infrastructure provision

Figure 8. Framework for adoption of smart waste management system in FCT.
Source: The author

The main aspects of the framework are explained in the sequence:

5.2.1 Management collaboration

Waste management in the FCT is decentralised and categorised into three responsive administration: the Abuja environmental protection board, the Satellite Town Development Department, and the Area Councils. Notably, the city centre of the FCC records coordinated waste management approach with less compliance in the suburbs and satellite town. The three

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responsible organs need proper coordination and harmonisation of waste management processes to provide equal privileges to residents who live within or outside of the city centre. The era of ICT as enablers of smart city brings the need for collaboration between key players in city management (Mayangasari, L., and Novani, S., 2015).

5.2.2 Policy framework

The role of policy in administration cannot be overemphasised. In collaboration with relevant stakeholders in waste management, the Abuja Environmental Protection Board (AEPB) should develop policies. Leadership is required on the part of the AEPB in ensuring timely and correct implementation of the policy. It should be noted that the AEPB wield some enormous amount of respect within the environmental sphere and the sights of its van, puts residents who are non-compliant on edge. This must be sustained to ensure that the needed processes of implementing smart waste management are followed and implemented to the latter. This finding is in line with the assertion of Myeong et al. (2018) on the role of smart policies. According to the authors, policy framework is needed to effectively provide services to citizens.

5.2.3 Open governance

A crucial part of management is open governance. Government policies and initiatives documents should be made accessible to the public if compliance is sorted after. A critical aspect of the finding is that no resident has seen the Abuja Master Plan. The only clue of its availability is seen when demolitions are carried out on houses supposedly built on a wrong land allotted for something else other than residential. Whatever may be the reason, residents need to have easy access to policies and framework to be able to comply as smart waste management cannot operate in a vacuum. According to Bolivar (2016, 392), “smart city governance is about crafting new forms of human collaboration through the use of ICTs to obtain better outcomes and more open governance process”, and this is said to be a major challenge in the execution of SC initiatives (Joshi et al., 2016; Guedes et al., 2018).

5.2.4 Residents-centricity

Smart waste management system is nothing more than a conscious effort toward efficiently managing waste from its generation to disposal. The success or failure of this initiative largely depends on residents' dispositions and ownership of such a project. Whatever technologies or processes are to be adopted, residents' opinions should be sort for. Residents can take responsibility for ensuring the security of any property within their locality if they are seen as co-owners. Also, irrespective of the new approach adopted for waste management, compliance on the part of residents is essential for effectiveness of such a policy hence, citizens need to accept before they are compliant. This finding conforms to the assertion of the integrated sustainable waste management of Klundert and Anschutz (2001); Wilson et al. (2013). Also, this finding supports the open innovation eco-systems approach of knowledge transfer between multiple stakeholders aimed at innovating products and new ways of service delivery (Bacon et al., 2019). As argued, open innovation deals with real-life issues identifying and designing new products and infrastructure in the settings' context (Leydesdorff and Deakin 2011; Durst and Poutanen, 2013). In an attempt to improve service delivery and management, a shift from the ideology of an organisation being a definer of value to a more participatory process whereby organisations and people together, generate and develop solutions is known as co-creation (Ind and Coates, 2015. Co-creation, facilitated by the use ICT, has seen the coming together of administrators and users as value creators (Ind and Coates, 2013). Sharing this same view of governance as a focus, the association between various stakeholders are said to be the defining characteristics of a smart city (Albino et al., 2015). Often called interactive governance, Torfing et al. (2019) described it in the network literature as the coming together of different stakeholders varied interest toward achieving a common objective geared toward producing public value.

5.2.5 Technology adoption

From literature on smart waste management reviewed, various ICT technologies are being used for waste management (see table 1). Mobile applications, as well as designated phone lines, should be considered while adopting data acquisition technologies. With the cost of implementing the SWMS being identified as a possible challenge, the AEPB should consider developing a mobile app where residents can always use to report when waste in their locality needs to be disposed of. The app could be used to track the estimated real-time of their waste collection and report to administrators in the event of delayed waste pickup. Also, the identified infrastructure deficit of power supply and reliable internet connectivity, designated phone lines could be used to call or send messages when services are required in a particular location. This takes the process from technology-dependent to tech-users methodology. Whatever the case is, administrators who are in a position of selecting what technology should be used should consider the mechanism behind its use. These findings align with Caniato et al. (2014); Myeong et al. (2018) on the need to consider the financial capability and available infrastructure before deciding which technology to adopt.

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5.2.6 Infrastructure provision

Waste management goes beyond how waste is collected to how such is treated. While the findings revealed that waste is currently not being treated, there is a need to equip the identified dump stations with facilities for waste sorting and treatment. More so, the FCTA through Department of Engineering services should consolidate the efforts of STDD and AC by converting the open dumps to closed ones. Also, the current plan on having transfer stations at locations other than landfills should be reconsidered as this will only increase the cost of waste management. This is so because a waste driver will be required to take waste to a specific treatment plant, and after each treatment, the dust is then driven to dumpsites. But suppose, the initial cost of equipping each of these various landfills with this treatment equipment is incurred. In that case, it will enhance efficiency in the short run and save cost in the long run.

Another critical aspect of infrastructure provision is the accessible road network. The FCTA should collaborate with relevant stakeholders to ensure that good and motorable roads are provided within the FCT. Myeong et al. (2018) argued that, if a smart initiative is to be achieved, urban infrastructure cannot be overlooked. The aim of SC initiative is focused on the "utilization of networked infrastructures to improve economic and political efficiency and enable socio, cultural and urban development." (Hollands, 2008, 307).

5.2.6 Regulatory enforcement

The existing regulatory frameworks on waste management need to be strengthened with strict enforcement. One major finding from the administrators' point is compliance. According to the report, some residents are deliberately not abiding by the dictate of the AEPB guidelines, which sometimes leads to litigation before having to comply. Also, residents who took part in this research reported that there are many regulations in place, but lack of strict enforcement causes reinforces non-compliance attitudes on the part of residents. Hence, where penalties are absent, laws should be enacted with prescribed stringent penalties for defaulter, as Zhang et al. (2019) recommended. The processes involved in the proposed framework is a continuous cycle; all aspects should be considered and reviewed as many times as possible.

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5.3 Study limitations

This research was carried out under certain circumstances, which may affect this study. In interpreting the findings of this research, it is pertinent to note the following limitations. First, the designated developmental phases of Abuja were not completely covered in this research. Phase 4 even though houses squatters' settlement was not considered in this research because official development was yet to commence. Second, the identified phases in the FCT have many districts and neighbourhood centres, but in selecting interviewees for this research, that was not considered and as such, it would be difficult to generalise the findings of this research as being an adequate representation of the subject. Third, the author was not able to interview waste management administrators within the area councils (AC) and the Satellite Town Development Department (STDD), to get their views and programs if any, as relating to waste management. Several contacts were made via emails and phone calls, but audience was not granted. Due to the difference in location, the interviews were conducted via zoom thereby making the whole process internet dependent. At some points during the interviews, there were network disruptions which led to situations where the interviewer requesting the interviewee to repeat things already said and, in the process, some important words were lost as its almost impossible to recount word for word. Finally, the author could not have access to the Abuja master plan since it is not made, a public document but relied on reports and interviews with custodians of the document.

6. CONCLUSION

This thesis attempted to create a framework for the adoption of a smart waste management system, taking into consideration the unique attributes of Abuja. This study answered the Research Question 'How to improve the Abuja waste management system using smart waste management system' by analysing the provisions of the Abuja master plan in relation to waste management (section 4.3.1); assessing the existing waste management practices in the Federal Capital Territory (section 4.3.2); researched on possible factors that could hinder the adoption of a smart waste management system (section 4.3.3); the roles of stakeholder involved in waste management eco-system (section 4.3.4); and proposed a framework for adoption of smart waste management system in Abuja (section 5.2). The framework suggests a continuous cycle with no prioritisation of any specific element. The framework was built based on documents analysis and data obtained through 13 interviews.

Following the adoption of a single case design, three main phases were carried out to achieve the objective of this study. The first phase was a literature review (Section 2), made up of a literature review to identify and describe the characteristics of smart city and urban waste management and applicable models. The second stage was data collection and analysis, which occurred in two steps (section 3). (i) knowledge-based, through analysis of documents which dealt with Abuja master plan. (ii) residents of Abuja and waste management administrators were interviewed to test their knowledge on the research topic and gathered information relevant to answering the research questions. Data collected were presented and discussed in section 4.2. The last phase was discussion (section 5) of findings. The Research Question Data Analysis online tool was used to highlight keywords and expressions common among respondents from analysis of feedback from interviews.

The reason for phrase identification was to bring to the author's attention, the possible areas of focus as a possible roadmap in understanding the peculiarities of Abuja. The author summarised important terms and factors identified during analysis of the transcribed interview recordings which are: management collaboration, policy framework, regulatory enforcement, open governance, user-centricity, technology adoption, and infrastructure provisions. A framework for the adoption of the smart waste management system was proposed based on the listed factors.

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The study has a practical and academic contribution. As practical, it has identified the main waste management practices in Abuja. Findings revealed that a) residents dispose of waste themselves, b) residents engage individuals known as scavengers for waste collection, and c) approved waste collection agencies. How the waste collected is disposed of include: waste burning, illegal waste disposals, and approved dumpsites. Abuja has various waste management practices which are not efficient despite being a planned city. Apart from the city centre, management of waste collection and disposal rest on the residence.

Other findings made include first, there is no single waste treatment plant, only one out of the two designated landfills in the AMP is used as a dumpsite. Second, the Area councils within the FCT operate open dumpsites, thereby being a source of environmental hazards. Third, residents do not have access to the Abuja master plan. Moreover, open governance is essential for residents to know the contents of policies that could inform their compliance. The academic contribution is that there is no study focusing on Abuja waste management practices and offers a framework for adopting a smart waste management system. The administrators of the FCTA, other states government and private organisation, stand to benefit from this research. For the FCTA and other state government, this research highlights the prevailing practices and factors that need to be considered while conceiving smart waste management. On the other hand, residents believe that it should be privately, or public-private-partnership driven for smart waste management implementation and operations to be effective. Hence the concept of co-creation.

This study shows that stakeholders understand the negative impact of improper waste management. They are willing to embrace innovative approaches geared towards protecting and promoting a cleaner environment. While there are plans underway to incinerate waste, energy recovery should be considered. The amount of waste generated could be converted into electricity from controlled thermal waste treatment plants. Considering the possibility of generating electricity through waste, open waste burning in practice at most of the open dumpsites and residential areas should be discouraged by providing and supervising these technologies required for the effectiveness of the smart waste management approach.

Lastly, as a suggestion for future work, there is a need for a further study focusing on the technical design of a prototype for smart waste management in the Abuja context and considering the possible challenges that need to be addressed to adopt the proposed framework successfully. Also,

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there is a need for a further study with a broader population to give room for a more diverse pool of interviewees leading to a more generalised result.

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APPENDICES

Appendix 1. Semi-structured interview guide

Section 1 – Segmentation Questions

1. Can you briefly introduce yourself?
2. What is your role/main responsibility in this organization?
3. How long have you been in your position?
4. How long have you resided in Abuja?

Section 2 – Abuja master plan x-ray

5. How familiar are you with the Abuja master plan?
6. Does the Abuja master plan incorporate waste management?

Section 3 – Current waste management flow

7. Can you give a brief explanation of how the waste management process works in this organization/area?
8. How many landfills are there in Abuja?
9. Are there waste recycling plants in Abuja?

Section 4 – Questions about Challenges faced by the current process and stakeholders.

10. What does the waste management flow currently look like?
11. How much of this flow will allow for digitalization in your opinion?
12. What challenges do you encounter with the current waste management system in use?
13. What is your organization doing to improve the current system?
14. Are they aspects of the current system that you think work well and should be improved on?
15. Who are the stakeholders involved in the current waste management flow (from waste collection to disposal)?
16. What are the roles of these stakeholder?

Section 5 – Questions about the introduction of smart waste management

17. How well do you understand the concept of smart waste management?
18. In your opinion, do you think an introduction of smart waste management will improve waste management processes?

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19. What do you think might be a major challenge adopting and implementing smart waste management?
20. How do you think these challenges can be addressed?
21. Generally, what building blocks need to be in place to allow for a smooth introduction of new technologies for waste management in Abuja?
22. What aspect of waste management process do you think smart technology will impact the most?
23. Will you accept the changes this impact will make to the current process?

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Appendix 2. List of Interviewees

Interviewees Identifier	Residential Area	AMP Code	Interviewees Occupation	Representative Organization
A01	Phase 1	A0	Self-employed	Resident
A02	Phase 1	A0	Public servant	Resident
B01	Phase 2	B0	Accountant	Resident
B02	Phase 2	B0	Public servant	Resident
C01	Phase 3	C0	Journalist	Resident
C02	Phase 3	C0	IT personnel	Resident
E01	Phase 5/ST	E0	Public servant	Resident
ST1	Satellite town	NA	Entrepreneur	Resident
ST2	Satellite town	NA	Accountant	Resident
ST3	Satellite town	NA	HR practitioner	Resident
ST4	Satellite town	NA	Civil servant	Resident
G01	NA	NA	Deputy Director	AEPB
G02	NA	NA	Site Officer	Development Control

Source: The Author.

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Appendix 3. Interview Recordings

Click on the link below to access the recorded interview sessions for this thesis:

https://drive.google.com/drive/folders/147htxwFSNcktU2up8v27dvaHrLUlkZb1?usp=sharing

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Appendix 4. Interview Transcript

Find the transcripts to the interviews conducted by clicking on the link below:

https://drive.google.com/drive/folders/1v0dIQFjgwakQWgKWctK75VQdEr1vIwro?usp=sharing

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Appendix 5. ICT tools and their applicability in smart waste management

ICT categorization	Sub-category	Applications
Spatial technologies	GIS	Site selection; designing; optimization; estimation
	GPS	collection and route design; vehicular tracking; schedule; planning
	RS	Site selection; ecological impact assessment; monitoring
Identification tech.	RFID	Monitoring; enhancement; sorting; recycle.
	Barcode	Recycling; waste disposal; risk management; reduce landfill space
Data acquisition	Imaging	Route and collection enhancement; sorting; monitor
	Sensors	Optimization; sorting; scheduling; energy/odour measurement; moisture
Data Communication	Bluetooth	Communication at a short range
	GSM/GPRS	Communication at a long range
	VHFR	Communication at a long range
	ZigBee	Communication at a short range

Source: Hannan et al. (2015, 111).

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