Waste Technology (WasTech)
Journal homepage: http://ejournal.undip.ac.id/index.php/wastech
An International Journal

A Proposed Digital Control System Using a Mobile Application for Municipal Solid Waste Management in South Africa

Adeleye Ayoade Adeniran[1*], Winston Shakantu[1], Emma Ayesu- Koranteng[1]

[1]Nelson Mandela University, South Africa
Email: ayoadeniran111@gmail.com

Abstract - *The generation and handling of waste are significant challenges to developing nations like South Africa. Studies show that improper disposal of waste results in un-aesthetic, unhygienic and other health-related issues in developing nations. In addition, waste is usually generated as a result of daily activities of humans and animals; and in developing countries, the generation of waste per unit of output is much higher than that of the developed countries; and coupled with this is the challenge of effectively integrating a solid waste management system in South Africa. This paper reviewed and analysed literature to provide a theoretical framework for understanding waste and the role that digitisation could play in its management. The research shows that sustainable and digital waste monitoring can be achieved in South Africa if there is a proper plan, effective environmental policy and cooperation between the government, private sector, partners and the citizens. Moreover, if waste handling can be harnessed into a local economic development opportunity, its handlers and generators could be persuaded to manage the waste differently and properly. This would, further, create employment and revenue generation opportunities as well as a greener environment.*

Keywords *– Waste Management, Waste Control, Digital Waste Control, Mobile Application*
Doi: http://dx.doi.org/10.14710/wastech.10.1.30-42
[How to cite this article: Adeniran, A.A., Shakantu, W., Ayesu- Koranteng, E. (2022). A Proposed Digital Control System Using a Mobile Application for Municipal Solid Waste Management in South Africa. Waste Technology, 10(1), 30-42 doi: http://dx.doi.org/10.14710/wastech.10.1.30-42]

1. Introduction

Waste is inseparable from all human activities (Adeniran, Adewole & Olofa, 2014), and they are generated from industries, manufacturing processes and domestic uses (Demirbas *et al.*, 2016). Therefore, the classification of waste according to Maity (2015) are solid waste, liquid waste and gaseous waste; and they include any garbage, refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded materials including solid, liquid, semi-solid, or contained gaseous material, resulting from industrial, commercial, mining and agricultural operations, and community activities, and any other activities in the entire area.

In simple words, solid waste is any discarded or abandoned materials, and examples of solid wastes include; waste tires, septage, scrap metal, garbage, latex paint, old furniture and toys, appliances and vehicles, oil and anti-freeze, empty aerosol cans, paint cans, compressed gas cylinders, construction and demolition debris and the like.

Solid waste is a vital responsibility of the area council government (Iyamu, Anda and Ho, 2020; Sambo, Muchindu, Nyambe and Yamauchi, 2020; Ogutu, Kimata and Kweyu, 2021) and one of the greatest challenges facing urban authorities today (Serge-Kubanza,2021). The volume of waste generated exceeds their technical and financial capacity to collect and dispose of solid waste, which can also have a significant negative impact on the environment and health of the citizens (Karak, Bhagat and Bhattacharyya, 2012). Uncollected and mismanaged solid waste provides a breeding ground for vermin and insects that proliferate and contribute to air and water-borne diseases Nor Faiza *et al.,* 2019). Cheremisinoff (2003) indicated that unsanitary disposal often leads to escaping leachate, causing further contamination of groundwater and soil resources, while open burning leads to the release of toxins and particulates such as black carbon. Also, Liu, Sun and Liu (2017) documented that waste management and disposal emissions represent a growing percentage of urban greenhouse gas emissions. However, Van Fan et al. (2021) argue that the action to reduce these impacts will be

critical as waste generation is growing faster than any other environmental pollutant, including CO_2, particularly in the developing regions where waste represents a larger share of overall emissions.

There is no definition for "digital waste management" from literature as it is an emerging term. However, this study will define it as all about using social media and the web as a tool to report and track waste collection levels by the governments and individuals responsible for collation in each area. Technology and digitisation have created business opportunities for waste management beyond its traditional trash collection business. For example, using expertise developed using mobile software and platforms like physical asset management and GPS-fleet tracking capabilities, digital waste management can be carried out to design and manage a logistics business and achieve fleet-optimisation and time management citizen participation and tracking solutions for its customers. Similarly, it is a way of making more money efficiently, and it makes running the waste management business more profitable.

Using mobile applications in reporting cases of overflowing bins, burning containers, and littered areas would help the contractors in charge of packing garbage keep up with the task, knowing in advance the areas that need more attention and leaving the area with less debris available to be packed. This would also increase citizen participation in the development of society.

Berg *et al.* (2020) opined that digitising the activities of the waste sector can significantly contribute to the creation of new jobs, mitigate environmental and health impacts and improve the economy as a whole. On the other hand, *Kaza et al.* (2018) reported that the management of solid waste is commonly the largest single budget item for cities and often one of the largest sectors of employment, and Brown, Milke and Seville (2011) stated that poorly managed waste has significant impacts on health, as well as on the local environment and the global environment (e.g. greenhouse gas emissions, water quality, soil health, biodiversity). Furthermore, Abdel-Shafy and Mansour (2018) also posited that improperly managed waste commonly results in the necessity of adopting higher cost solutions (i.e. remediation) compared to the solutions that could manage the waste properly.

Digitising the waste sector, therefore, could help in documentation for future use as it would monitor the tons of waste and the different types of waste collected from different areas and would also encourage the active participation of the citizens in the delicate issue of a cleaner environment (Berg *et al.* (2020).

Hence, there is a need to change the mindset that considers solid waste liability and develop a mindset and vocabulary around solid waste and its digitisation as a potential resource for generating economic activities, diversifying risk, creating jobs, and improving the environment human welfare. In order to shift the paradigm, long-term waste management and control strategies are needed. As such, the long-term digital waste management strategy should cultivate a new culture that advocates the use of mobile and web applications to report and track waste collection, integration of waste avoidance, minimisation, recycling, reuse, and reporting waste litters to ensure and enforce swift responses.

This paper reviews the literature to provide a theoretical framework for digitisation's role in waste collection.

2. Significance of the Research

While waste management systems have evolved over the decades, the uptake of new software technologies for improved and efficient waste collection and transportation services is a relatively new phenomenon (Berg *et al.,* 2020). Without proper data collection and management systems, it is challenging to have a sound, transparent waste strategy. Hence, cities need to acknowledge this and adopt software technologies to manage solid waste and create a database of knowledge to generate further positive changes (Wilson *et al.,* 2012). However, Kurniawan *et al.* (2021) elaborated that cities are yet to understand the roles of digitisation technologies in the 4th Industrial Revolution for waste reduction in the circular economy framework and hence do not currently utilise it. In addition, according to Ringenson et al. (2018), many municipalities express a wish to use digital technologies to achieve environmental aims, but this still requires an understanding of its workability by both the municipalities and among ICT developers.

Digital solid waste management would help authorities remove waste or garbage alone and monitor the daily activities undertaken. Data from this can be used in the future to allocate new resources to areas with more waste and deallocate resources to areas with less waste generated. It would also help engage the citizen to contribute their quota by reporting and helping ensure a cleaner and healthier environment.

3. Problem Statement

According to reports, South Africa, with a population of approximately 59.62 million, is an economic/industrial hub in Africa that generates more than 54.2 million tons of solid waste annually. However, only 20-30% of the total waste generated is collected, and 10% and 90% of the collected waste is recycled/recovered and landfilled/dumped, respectively. Some of these wastes generated by households, traders, artisans, and local industries litter their immediate surroundings. It is observed by Dauvergne (2018) and El Bastawesy, Adel and Mohamed (2018) that the improper management of waste generally leads to blockage of drainage and sewer networks, as well as chocking of marine bodies. Furthermore, in the face of dwindling budgetary provisions for implementing integrated waste management programmes nationwide, the improper collection and disposal of municipal wastes continue unabated on the path to an environmental catastrophe (Maluleke, 2014).

It is indicated that the population of African cities tripled between 1950 and 2018, and such cities are currently overwhelmed with slums which could be catastrophic if vital actions are not initiated (UNDESA, 2019). In South Africa, all nine provinces, particularly the metropolitan municipalities, have demonstrated a significant proactiveness towards fighting this scourge with their different waste management policies (Khwene, 2020). However, although it is generally agreed that waste management services are essential services that must be provided in every society, waste still dots the landscape. As such, the policy documents' objective does not seem to be commensurate with waste management in real life, and this continues to pose a great risk to the health of inhabitants and the environment.

Hence, it is important to have a clear guide to what could further enhance waste management systems. One such method that has been touted as effective in enhancing waste management and therefore proposed a solution by this research is a digital control system.

4. Literature Review

This section reviews the literature on waste, management, and digital control challenges. With increased urbanisation stimulated by population growth, improved living standards, change in lifestyle, and modern facilities and infrastructure in the urban centres come to a significant increase in waste generation, resulting in high environmental pollution (Amo-Asamoah, Owusu-Manu, Asumadu, Ghansah and Edwards, 2020). Developed countries have developed better solid waste collection systems than developing and third-world countries. One such system is the digitisation of solid waste management, where the people contribute by using mobile platforms to report cases of burning debris or overflowing debris left unattended. Abdel-Shafy and Mansour (2018), as shown in Figure 1, illustrated the waste composition and classification (by material) of municipal solid waste generated by the United States in 2013.

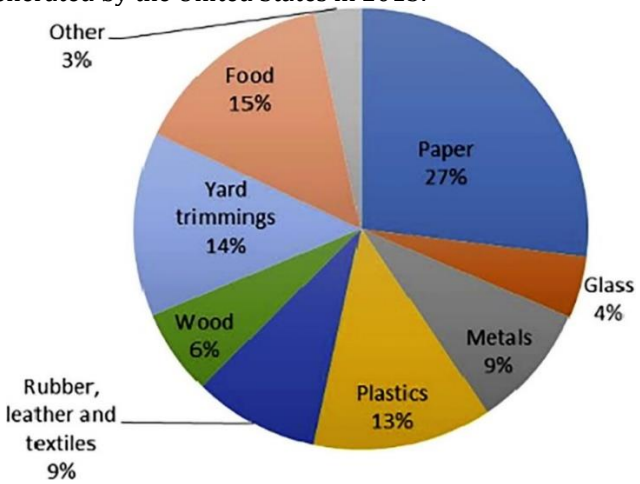

Figure 1. Composition and classification (by material) of MSW generated by the United States in 2013 (Abdel-Shafy &Mansour, 2018).

Wong (2020) reported that China had surpassed the United States as the country that generates most waste with a record of 242 million tons annually in 2019 and a predicted 480 million tons annually by 2030. Also, the increase in new waste constituents such as e-waste and polythene/cellophane materials shows that these less biodegradable materials pose a critical challenge for the already overwhelmed municipal solid waste management in various cities (Mapa, Powell, Asis, Sakke and Gulasan, 2019). Furthermore, the ease of conveying waste and generating income has given rise to a new method of disposable packaging wherein consumable products come in disposable packs that end up as waste (Szaky, 2019). Unfortunately, most of these packages are non-biodegradable, and their disposal has given rise to the proliferation of open dumps, which constitute a grave environmental and health hazard (Muhumuza, Ongodia and Namara, 2012, Kharlamova, Mada and Grachev, 2016, Ferronato and Torretta, 2019).

Asase *et al.* (2009) posited that developing countries' municipal solid waste management is often characterised by insufficient service coverage, inefficient administrative and operational framework, inadequate recycling and landfill disposal. The digital control of waste management could help ensure that the mechanism for waste processes is deployed as needed rather than the "current scheduling" practice. For example, Godfrey *et al.* (2019) reported that urban centres enjoy better waste collection services while services in the suburbs and peri-urban areas are usually poor and those of rural areas are worse or non-existent. Nkosi, Muzenda, Zvimba and Pilusa (2013) stated that solid waste management is a growing environmental problem in developing countries like South Africa as the municipalities cannot keep pace with the volume of waste generated. They posited that the increased waste is due to the increased standard of living and economic growth. Kasinja and Tilley (2018), in the study of waste generated in Lilongwe City, Malawi, observed that the waste had surpassed the capacity of the city council in terms of human resources and infrastructure, which has resulted in a decline in the quality of solid waste management. The inefficiency of the Kenyan waste collection and disposal systems are not environmentally friendly such that between 30 and 40 per cent of urban solid waste is uncollected, with less than 50 per cent of the populace served (Gakungu *et al.*, 2012). For the Arab countries, the amount of municipal solid waste generated is about 81.3 million tons per year; less than 20% is adequately treated, and less than 5% is recycled (Mostafa, 2020). Alam (2016), however, argued that if the current capacity and resources are strategically deployed with governance systems and processes designed more appropriately, the currently perceived incapacitation of the municipality will be overcome.

In South Africa, based on specialisation and research interest, several studies have been carried out on municipal solid waste management, with each of them adding to the global body of knowledge of solid waste management. This

study, however, attempts to combine their findings into a comprehensive description of South Africa's solid waste management.

On record, South Africa, as a developing nation rising from its apartheid past, is grappling with so many challenges: the hazard of increasing municipal solid waste, both in diversity and quantity (Sibran, 2019).

Department of Environmental Affairs, DEA (2018) highlighted the contribution of each waste type to the total tonnage of general waste generated in 2017. The largest contribution to the total quantity of general waste was 'other' 35% which comprises biomass predominantly from paper and pulp industries as well as sugar mills. This is followed by organic waste (16%), construction and demolition waste (13%), scrap metals (8%) and commercial and industrial waste (7%). It is worthy of note that general municipal waste only accounts for 4% of the total general waste as organic, paper, plastic, glass, scrap metal, and tyre wastes were reported separately where possible (see Figure 2).

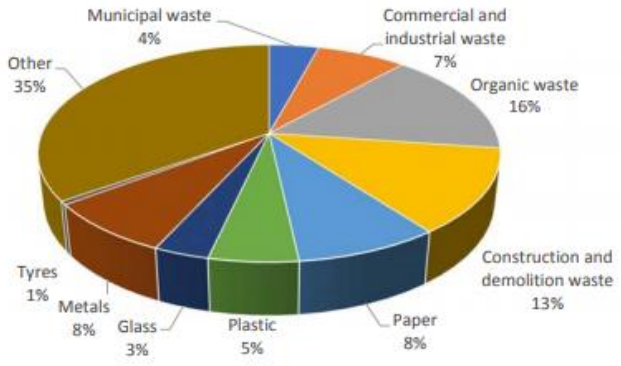

Figure 2. Breakdown of waste generated in 2017 (Department of Environmental Affairs, (DEA), 2018)

Stopka, Stopkova and Kampf, (2019) identified the cycle of municipal waste management as generation and storage, disposal, collection and transfer, sorting, treatment, material recovery and disposal. The challenge of collection and disposal of waste is so annihilating that it overshadows all other aspects of waste management, and the reuse and recycling of waste materials are carried out on an informal basis (Asase *et al.* 2009); hence, it is safe to deduce that waste management can be an indicator of the level of development of a country. Rizk and Slimane (2018) inferred a direct relationship between poverty, the state of the environment and institutions. Despite the importance of waste management, it is, however, usually ranked after other issues such as food, water, health, employment, education, urban infrastructure and security and has thus received less attention from policymakers and academics than other environmental problems (Fuss, Barros and Poganietz, 2018).

Global population growth, economic development, urbanisation, and industrialisation contribute to the increased volume of solid waste whose handling is complex and potentially hazardous to humans and the environment. For example, Kaza, Yao, Bhada-Tata and Van Woerden (2018) projected that by 2050, the world is expected to increase waste generation by 70 per cent, from 2.01 billion tonnes of waste in 2016 to 3.40 billion tonnes of waste annually. The substantial growth in the volume of solid waste generated globally with its attendant impact on human health and the environment have thus stimulated the necessity for efficient and effective waste management systems by stakeholders (Soltani, Hewage, Reza and Sadiq, 2015).

The absolute reduction and prevention of waste should be an urgent priority for every municipality in South Africa, even though it is capital intensive. This research intends to get everyone involved so as to improve the environment and keep a healthy society.

Using contingent valuation method surveys (CVMS), many studies provide evidence that households are willing to pay a significant amount for the provision of improved waste management (Tassie and Endalew, 2020). For example, Kinnaman (2009) reported that households in three squatter villages in Malaysia are assessed to be keen to pay $3.42 monthly for a consistent waste collection rather than indiscriminate discarding. Also, a survey of low-income households in Nigeria is estimated to be willing to pay $1.70 – $1.80 monthly to have their waste collected regularly (Ighalo and Adeniyi, 2020). Moreover, the willingness to pay for basic solid waste management collection is generally appraised to increase the household's income (Tarfasa and Brouwer, 2018). Hence, the primary focus of developing countries is on establishing proper collection and disposal methods and not on evolving policy strategies to increase recycling. This paper is premised on the argument that adopting a digital control system using a mobile application for municipal solid waste management could aid developing countries in this feat.

Franklin, Powell and Workman (1998) indicated that controlling physical systems with digital workstations is becoming common with mass transit vehicles, oil refineries, and aircraft. According to Isaksson, Harjunkoski, and Sand (2018), microprocessor technology stimulates digital control applications that control many parts of automobiles and home appliances, resulting in enhanced flexibility of control programs and decision-making integrated with the dynamic control function to satisfy other system requirements.

In the field of digital control, the concept of "digitisation" and "digitalisation" are interlinked, and literature often uses them interchangeably. Brennen and Kreiss (2016) argue that "digitisation is a material process, focused on converting analogue streams of information into digital bits while digitalisation is about social life restructuring around digital communication and media infrastructures. This paper supports their argument and finds it valuable for stressing the distinction between the technological environments necessary for the actual change

(digitalisation) and the digitally linked societal change (digitisation). The former is usually denoted as digital transformation. However, digitalisation and sustainability are sub-topics that are gaining attention in the manufacturing research domain, and they are both shaping the future systems (Maffei, Grahn and Nuur, 2019), which are very relevant for waste issues. In addition, Isaksson, Harjunkoski and Sand (2018) underscored that digitalisation intensifies the necessity for optimisation. Optimisation of the waste management system is expected to yield the desired aim of the waste management process.

While the tentacles of digitalisation are growing globally, its use and application differ between cities, regions, and countries depending on the devices, access, governance, and culture (Afradi and Nourian, 2020). Moreover, their implementation for sustainable cities is impacted by these factors (Bibri and Krogstie, 2017) and may pose challenges that stakeholders have numerous ideas of how to tackle (Höjer and Wangel, 2015). Consequently, it is crucial to support different actors in discerning the cities' challenges so that solutions can be found for them. Hence, if the latent potential of digitalisation is going to have a positive influence, cities and actors need to harness technology at its best within a specific context (Shruti, Singh and Ohri, 2021) and bring to fore better cooperation between information and communication technology segment and the authorities (Goulden *et al.*, 2018).

5. Methodology

The methodology utilised by this study is discussed in this segment to give a view of how and what was done. As is the case with desktop research studies where existing data are used for analysis and to draw vital conclusions, this paper relied immensely on secondary data. Some of the data sources for the study include journal articles, unpublished papers, reports, webpages and books. This research approach is employed when extensive work has been carried out on a research topic and when the study aims to answer specific questions based on previous works. For these reasons, this paper utilised this approach to examine what different researchers have said on waste, its types, waste minimisation, and its management. Some of the vital published works this research consulted include the following Mngomezulu (2020), Rodseth, Notten and Von Blottnitz (2020), Kotze (2020), Dlamini, Simatele and Serge Kubanza (2019), Godfrey and Oelofse (2017), Godfrey *et al.* (2017) Simatele, Dlamini and Kubanza (2017) and Gumbi (2015).

6. Discussion

This section specifically reviews study findings from research conducted around South Africa to underscore the challenges inherent in the country around waste and its issues. Gumbi (2015) conducted an exploratory study on current waste management and minimisation patterns and practices in the Ekurhuleni Metropolitan Municipality in South Africa. The scope of the research submitted in fulfilment of a Masters' degree includes identifying and analysing existing waste management and minimisation and the willingness of the respondents to participate, as well as the constraints hindering effective waste minimisation in the study area. Gumbu identified the different types of waste generated and disposed of at the household level to include cardboards (36%), food waste (18%), plastic (14%), glass (8%), organic waste (7%), tins (4%), scrap metal (4%), newspapers (3%), white paper (2%) and cartons (2%). The author acknowledged that most of the waste generated is related to the product packaging (e.g. plastic, glass, cartoons) from manufacturing companies and food leftovers, as well as spoiled food that was never consumed. The study established the willingness of participants in the minimisation of waste and identified the barriers to include lack of adequate resources such as waste bins that enabled the separation of waste at source, thus not encouraging households to sort their waste; municipality defaulting in maintaining the set collection schedule which leads to illegal dumping by communities; lack of adequate waste skips which households can easily access; lack of waste management awareness campaigns to sensitise the communities about best practices of waste management; the building of buyback centres easily accessed by informal waste reclaimers in order to encourage the continual recycling activities as well as having control of the recycling activities; and lack of enforcement of waste bylaws which would discourage and minimise illegal dumping and litter. The implication is that the harnessing of the tools of digitisation could encourage not only households but every citizen to report on waste issue bearing.

Godfrey *et al.* (2017) studied co-operatives as a development mechanism to support job creation and sustainable waste management in South Africa and identified the challenges facing waste and recycling co-operatives. The study identified that waste and recycling co-operatives operate largely on the fringe of municipal solid waste management and are characterised by a high mortality rate and a high membership turnover despite the strong drive and investment being made by the South African Government to establish co-operatives as a development mechanism in the face of the current high levels of unemployment and a slowing economy, as well as to extend waste services to un- or under-serviced communities. According to their findings, the effect of this is in vain, given that with a 91.8% mortality rate, most of the registered waste and recycling co-operatives were no longer operating. Their results highlight access to funding, access to materials, access to markets, and business development support as the criteria considered crucial to creating a viable co-operative movement in the solid waste management sector in South Africa. The introduction of a digital control system could ensure that the co-operatives who sign onto the platform will only deploy their resources as needed, reducing their cost. Also, necessary personal

protective gears will be provided pre-waste removal as they will be aware of the type of waste to be removed hence reducing their exposure.

Simatele, Dlamini and Kubanza (2017) focused on the perception of informality and formality of the challenges of integrating solid waste management into the urban development and planning policy in Johannesburg, South Africa. The authors collected data in Johannesburg from September to November using seventy-three (73) waste pickers who were selected systematically from three purposely selected buyback centres, namely Maningi scrap metals, Far-point recycling and Remade recycling. Also, interviews were conducted through discussions and personal interviews with ten (10) key informants drawn from the Environmental and Infrastructure Services Department, the Department of Agriculture and Rural Development (Waste Management), Pikitup, Geza Jozi and Bathopele co-operative. Their study demonstrated that the informal waste sector plays a significant role in waste collection and recycling in Johannesburg municipal solid waste management. However, from empirical evidence, there is no significant progress in aligning and or integrating informal systems of solid waste management with formal systems. According to them, this is adduced to the rooted perception of the role of waste scavengers as "a nuisance" since many local authorities consider them as contributing to the increased littering of solid waste. They, however, posited from the findings of their study that the informal solid waste sector in Johannesburg is intricately linked through casualisation to formal firms and recommended that urban governance systems and structures in the city become more flexible with local authorities showing keen interest in supporting and linking both horizontal and vertical exchanges of best practices to bring out the effective and sustainable waste collection and recycling systems.

They further posited that until individuals and communities are empowered, and their activities are integrated into urban development and planning policies, the contribution to the informal solid waste collection and recycling would remain neglected and unrecognised. Creating a digital platform that every individual can access is a form of empowerment, and the informality could be monitored such that data is collected accordingly.

In the historical review of waste management and recycling in South Africa by Godfrey and Oelofse (2017), they stated that South Africa has effectively developed a recycling economy through four stages of the age of landfilling, the emergence of recycling, the flood of regulation and the drive for extended producer responsibility (EPR), over the past thirty years with a dint of hard work of a dynamic informal waste segment. However, they recognised that a lot still must be done considering the substantial waste quantities, including recyclables still being disposed of in landfills. They suggested that unlocking the social, economic and environmental opportunities provided by secondary resources has the stimuli to generate significant opportunities but also raised the questions of domesticating and commercialising a circular economy in a developing country context, such as South Africa and further questioned the opportunity for South Africa. To leapfrog the technology choices of developed countries, other developing countries move directly towards a stronger materials recovery paradigm. Digital transformation could be that technological leapfrog they referred to in their study.

Using Johannesburg as a case, Dlamini, Simatele and Serge Kubanza (2019) considered waste to energy recovery through waste-to-energy technologies in municipal solid waste management. They estimated that the city of Johannesburg's landfills space will be completely depleted by 2023, and this motivated them to identify suitable waste to energy (WTE) alternative avenues to manage waste in the city. They argued that WTE technologies could contribute significantly to sustainable waste management, economic growth, ecological and environmental well-being as the city currently generates electricity through the landfill gas recovery technology from existing and operating landfill sites. They suggested that besides landfill gas recovery, incineration technology for non-recyclable waste and anaerobic digestion of separated biodegradable waste should be considered to generate electricity further and broaden options for waste management in the city. This, they stated, will potentially earn carbon credits, create jobs, generate renewable electricity, and revenue from the sale of by-products.

Kotze (2020) investigated household behaviour towards waste management amongst the youth in Parys, South Africa. This author argued that the youth, as the nation's future citizens, should actively solve environmental issues. The Theory of Planned Behaviour (TPB) was used as a theoretical lens to understand the influencing factors of household waste behaviour. The quantitative study used a questionnaire and established that learners have a proper understanding of household waste and occasionally have a sense of responsibility towards the environment and recycle some waste by engaging in the reuse of items from household waste regularly. However, it was recommended that there be an increased environmental awareness by both the government and the public to minimise environmental problems with more efforts focused on creating a culture of more sustainable waste practices where every household produces waste and is hence part of the solution. It was also noted that households would be more willing to recycle if incentives were given and if recycling could be made more convenient in terms of the ease of the recycling process.

Rodseth, Notten and Von Blottnitz (2020) researched a revised approach for estimating informally disposed domestic waste in rural versus urban South Africa and implications for waste management. The study identified a current limitation in the availability of accurate and reliable national waste data and developed a basic mapping of

domestic waste flows hence providing an estimate for both formally and informally managed waste. Their results suggested that 29% of domestic waste generated by weight in the country is neither collected nor treated via formal management options, and of this waste, 85% is generated in rural areas. The study identified private dumpsites as the most common waste management option for unserviced households while others either dump illegally or managed through uncontrolled burning. They concluded that the lack of reliable South African specific waste generation rates reflects the paucity of focused waste generation studies undertaken in the region, and this parameter is expected to help with waste management issues. The digital control system could help here as the picture of waste captured by drone will help determine what service provider should pick the identified waste and report/document the waste typology to the appropriate designated office/platform.

Mngomezulu (2020) sought to identify management practices that would help address the limitations of sustainable solid waste management. The study was stimulated by illegal dumping and littering in the Joe Slovo West Township and other townships in the Nelson Mandela Bay Municipality (NMBM). From the empirical study carried out, it was noted that most of the respondents do not have enough knowledge of innovative and technological waste management practices. Finally, the literature derived from the conceptual framework showed a knowledge gap regarding waste technological systems. The study concluded that most solid waste produced by residents is recyclable, and the area lacks efficient waste management practices, which results in littering. It is also concluded that the commonly used storage material before disposal is plastic bags which raises a concern regarding environmental issues since the majority disposed of such waste without separating it. According to the study, some of the challenges facing existing solid waste management practices include lack of funding, the shortage of personnel dealing with solid waste, among others. The digital control system will enhance overhead cost reduction while ensuring that the available resources and personnel are deployed as necessary.

Hence, the reason for this study, which is grounded in the entire waste management cycle (see Figure 3) and its automation, is to proffer using an application that does the monitoring and keeps track of how the waste management office responds swiftly to notifications of the available waste to be disposed of. As illustrated in Figure 4, by the year 2025, tons of debris would have increased from 1.3 billion tons/ year in 2012 to 2.2 billion tons/year, as indicated by Bhada-Tata and Hoornweg (2012)

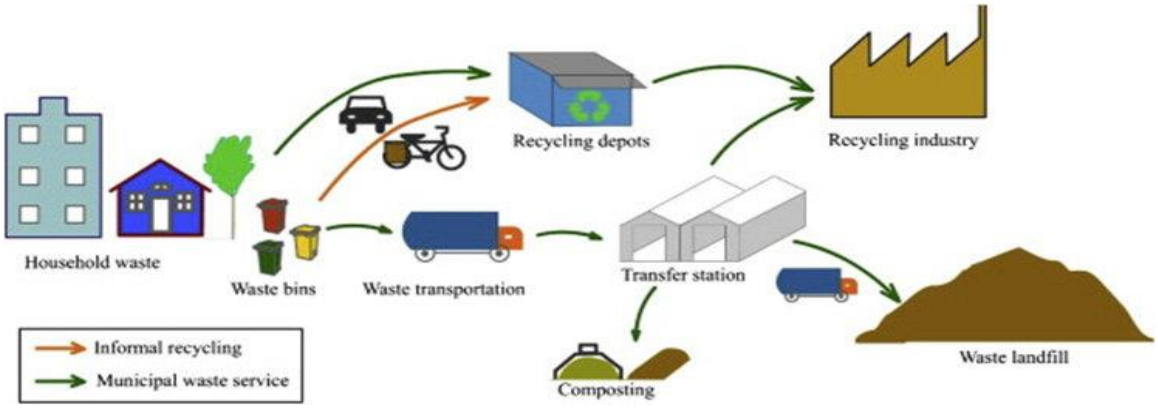

Figure 3. Waste management cycle (Amasuomo and Baird, 2016)

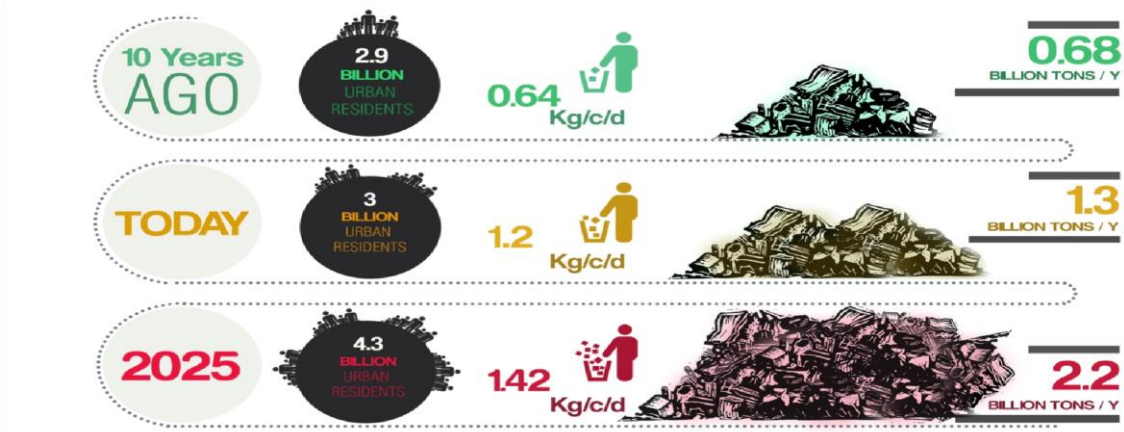

Figure 4. Municipal solid waste quantities (Hoornweg and Bhada-Tata, 2012 cited in Elagroudy, Warith and El Zayat, 2016.)

Due to the increasing population and the attendant solid waste generation, the management of waste is becoming a challenge for city authorities by the burden it places on municipal budgets; the lack of insight into the diversity of dynamics that affect waste management; and of the vital links to aid the functioning of the whole system. The primary challenges that must be surmounted in successfully implementing a solid waste management system include:

Solid waste management is a complex issue involving multiple stakeholders (Thyberg and Tonjes, 2015). Cities strive to solve the diverse challenges confronting them, but an effective waste management system needs to harness technological solutions within the environmental, institutional, economic, socio-cultural and legal milieu. Citizens participation must also be accommodated to create general awareness amongst the public.

In addition, while involving all the stakeholders towards holistic participation, some of them will have conflicting interests (Goulart-Coelho, Lange & Coelho, 2017). Hence, detailed comprehension of the stakeholders and their responsibilities in the waste management composition is essential to establish a successful structure. Also, effective communication amongst the stakeholders, particularly in developing country cities, is vital for creating a functional waste management system; consequently, there is a need for a central platform that involves all of them.

There are institutional challenges in many developing countries' solid waste management departments where they either lack the relevant skills or are understaffed (Simatele, Dlamini and Kubanza, 2017). These limitations often result in crude or unsafe disposal methods such as open burning, dumping, or landfilling. Hence, the capacity building becomes a necessary investment towards enhancing the quantity and quality of staff resources and skills.

It is critical to have policies and strategies ensuring that waste management offenders will be penalised when they violate any waste management laws, and such policies and strategies must be adapted to the needs of the local citizens. Furthermore, as a multi-billion-dollar sector, solid waste management can further upscale the economy (Ramos, Berzosa, Espí, Clarens and Rouboa, 2020) of a country like South Africa if the proper measures are taken since waste can be used to generate electricity when processed. The Public-Private Partnerships may be used in driving this.

Using digital applications, solid waste services would be extended to everyone because they can report using the digital platform whether they are technology inclined or otherwise. The advantage of this system is that there would be real-time information on waste issues and deployment of resources based on the actual needs. This is expected to reduce cost while optimising resources efficiently and improving air and environmental quality, i.e. less odour and cleaner cities. In addition, the government would organise training for people who are not technologically inclined, and there should be a separate Unstructured Supplementary Service Data (USSD) code that could be sent to notify the appropriate office of the overflowing debris or a burning refuse bin.

7. Proposed New System

The new system proposed is a digital participatory waste management service monitoring system (DPWMS) to reinforce reliability for the city's waste management services towards optimising user relations. The DPWMS proposed is a comprehensive smart-city network that warehouses, evaluates and dispenses information submitted by residents through a free mobile app, Unstructured Supplementary Service Data (USSD), short message service (SMS), and an accompanying website. The residents would take pictures or other images of waste irregularities and forward them through any of the platforms listed above to the designated authorities, who are expected to receive the same in real-time. In return, the designated authority is expected to swiftly respond to rectify the mess by either sending a drone within the area to assess the situation of the specific and surrounding area or dispatching needed attention. Figure 5 shows how the system is expected to work.

In summary, it is expected that the citizens would send a picture through the mobile application or USSD/SMS, and then the Digital platform receives and processes the information, which is sent to a drone within the identified location as captured on the image sent. The drone would survey the areas, and while its imagery is monitored on the dashboard, the municipality waste management worker or service provider would do the needful and then give feedback to the resident who reported the case. Hopefully, if the Municipal authorities in South Africa adopt this digital method, it would help resolve environmental issues; and it could be modified to resolve issues in other vital areas facing challenges areas like water, traffic and health management.

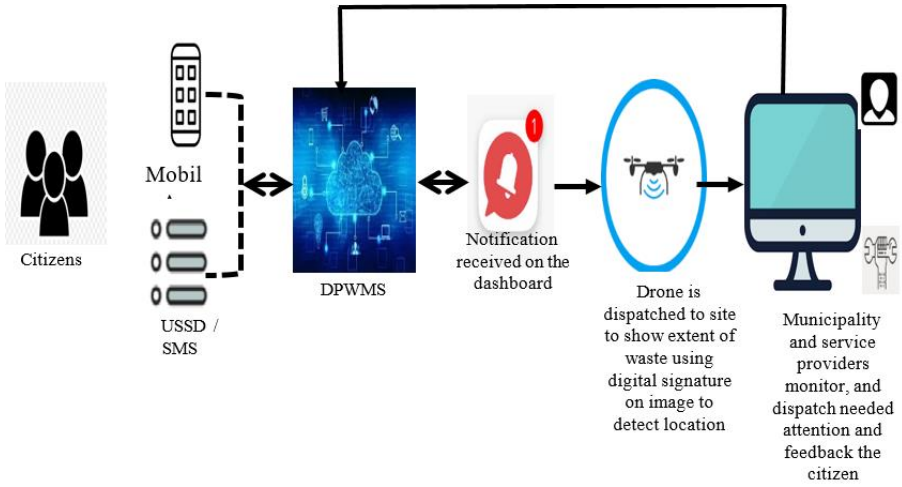

Figure 5: Proposed digital Waste management structure

7.1 Recommendations

To tackle the challenges identified towards harnessing the gains of a sound digital participatory waste management service monitoring system, a few further recommendations are hereby made:

i. Residents should be encouraged to proactively partake and collaborate in helping report cases of waste issues, and such participation may have a reward system for reporting such incidences.
ii. Resources should be harnessed for further research and the development of a digital participatory waste management service monitoring (DPWMSM) application piloted at communities where inhabitants would be educated on how to use the application for the benefit of the entire community.
iii. The DPWMSM would aid the development of a robust waste utilisation infrastructure, particularly in megacities where landfills space is limited, energy demand is high, and the landfills are distant. Furthermore, this method would aid in creating additional value for waste materials by combining sustainable waste treatment with the generation of clean local, reliable energy and resources.
iv. Innovative strategies for improving the waste collection can aid cities in significantly reducing costs, thereby re-allowing saved finance to other developments. This can be achieved through new and innovative technologies, improved collection channels and new routing systems.
v. While the waste management system has advanced over time, the acceptance of software technologies for improved and efficient waste collection and transportation services is quite a new phenomenon. It is challenging to have a sound and transparent strategy without a proper data collection and management system. Hence, cities must acknowledge this and adopt software technologies to manage solid waste, thereby creating a knowledge database to stimulate further constructive changes. It is important to underpin that databases are vital in the workings and correction of so many societal and environmental issues.
vi. A synergy of waste prevention and reduction, reuse of goods, recycling, and waste recovery is the backbone of a sustainable and integrated waste management policy. Such policy incorporates various methods to provide tailored waste disposal solutions for all types of waste. Hence, the integration of mechanical and manual sorting, recycling, and power-generating technologies presents vital interactions and economies of scale that may be unachievable if commissioned individually.

8. Conclusion

From the preceding, solid waste generation is a continuous activity, and the participation of inhabitants in reporting cases to the waste management office would do much good. Moreover, it would further reduce the cost, effort and time of deploying resources to places where they are not needed while such resources would be maximised in areas of urgent need.

The principal contributor to municipal solid waste in most South African cities is households, and as much as 69 per cent of solid waste generated (Gumbi (2015) is recyclable. With this volume of recyclable waste, implementing efficient digital waste disposal practices would aid in improving the condition of municipal solid waste management asides from the employment and economic benefit opportunities it would offer.

Due to challenges, poor funding and a dearth of trained personnel, waste disposed by unconventional means can block drains and result in flooding. This can be eliminated by ensuring that every household is encouraged to report irregularities, waste burning and overflowing waste dumps or areas with waste littering. Furthermore, to enhance efficiency in waste collection, digitalisation would help identify areas with poor accessibility and aid in planning facilities and increased participation of the private sector in terms of job creation via waste to wealth.

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