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A PERSPECTIVE OF INCORPORATING GIS IN WASTE COLLECTION IN INFORMAL SETTLEMENT TO COMBAT ILLEGAL DUMPING: SOUTH AFRICAN CONTEXT

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Abstract: Illegal dumping remains a persistent waste-management challenge globally, particularly in informal settlements of developing countries where municipal service delivery is inconsistent. In South Africa, inadequate and irregular waste collection has intensified the proliferation of uncontrolled dumping sites, creating substantial economic, social and environmental risks. This review synthesises existing empirical studies, policy documents and municipal case examples to examine the drivers of illegal dumping and evaluate the potential of Geographic Information Systems (GIS) to strengthen waste-management practices. A narrative review approach was adopted, drawing on literature sourced from Google Scholar, Scopus and Web of Science using search terms related to illegal dumping, GIS and informal settlements. Findings indicate that although GIS has been successfully applied internationally for hotspot detection, route optimisation and spatial monitoring of waste flows, its adoption in South Africa remains limited by insufficient datasets, technical capacity constraints, financial barriers and fragmented institutional coordination. Substantial disparities in waste-collection services between formal and informal settlements further exacerbate illegal dumping trends. The review identifies key opportunities for integrating low-cost, context-appropriate GIS tools to improve service delivery, facilitate proactive intervention and support evidence-based planning. Policy recommendations include establishing integrated geodatabases for informal settlements, expanding community-based reporting mechanisms and adopting GIS-enabled routing systems. Future research should prioritise predictive modelling of illegal dumping patterns and empirical assessments of GIS implementation across South African municipalities.

Keywords: GIS, Waste management municipality, Informal settlement, South Africa

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1. Introduction

Illegal dumping has become one of the biggest issues all around the world. It affects the living conditions in society, particularly the informal settlements of developing countries; thus, slows down the sustainable development of the country (Ogunmodede et al., 2014; Pacione, 2007). Pacione (2007) explains that the concept of sustainable development has been a challenge in many developing countries. Thus, finding it difficult to implement the measures of sustainability while still in the process of development, especially in urban areas where the majority reside in poor townships that are largely characterized by informal settlements.

South Africa is amongst the fastest developing countries faced with challenges of illegal dumping mostly in townships and in informal settlements found in metropolitan (Ngeleka, 2010). According to Yoada et al. (2014), the local government is responsible for the provision of waste management services in the areas under its jurisdiction. However, Antwi (2008) corroborated that the low-income communities receive inadequate service as compared to more affluent areas. This pattern is further confirmed by recent neighbourhood-level evidence: Ngalo and Thondhlana (2023) found that illegal dumping remains prevalent in low-income South African communities despite environmental awareness, largely due to inadequate municipal services, inaccessible waste collection points, and socio-economic constraints. A study by Selani (2017) indicated that the main factors contributing to illegal refuse dumping are insufficient waste removal services, delays in municipal collection, lack of formal waste

systems in informal settlements due to inadequate roads, insufficient skips, and long travel distances to disposal points. As a result, waste is observed piled up next to the waste skips which ultimately gets scattered all over the surroundings (Ejaz et al., 2010; Bhattacharjee and Polas, 2018).

This makes it easier for people to just dispose of waste in vacant spaces, along the roadside, and around waste skips which creates economic, social, and environmental concerns (Nkwachukwu et al., 2010; Agarwal et al., 2015). The environmental impact of illegal dumping is significant with notable environmental challenges which adversely cause a vast growth in health-related issues within communities (Rahman et al., 2008; Sibanda, 2019; Sule et al., 2014).

Concerning all the above mentioned, waste management practices of illegal dumping are ineffective in informal settlements even though there are regulations related to waste management. Thus, improving illegal dumping practices requires effort and to make progress, institutions need to embrace technological interventions that are adaptive such as Geographic Information System (GIS) that can solve a variety of problems (McAllister, 2015; Amakihe, 2011). A large number of existing studies in the broader literature have examined the application of (GIS) and remote sensing to deal with the issue of illegal dumping. This has been explored by Jakiel et al., 2019; Jimoh et al., 2019) which noted a significant success in combating illegal dumping when implementing these technologies. Moreover, although research has illuminated the successful implementation of GIS for good waste management practice in developed countries, it is insufficiently explored in South Africa particular in townships and informal settlement and remains to be tested to provide viable solutions for illegal dumping.

This review aims to critically examine illegal dumping challenges in South Africa's informal settlements and evaluate how GIS-based approaches have been applied globally and can be adapted to the South African context. The scope includes legislative frameworks, current waste management practices, and technological opportunities for improving waste collection efficiency and monitoring illegal dumping.

This study adopts a narrative review approach rather than a systematic review, given its conceptual aim of synthesising policy frameworks, empirical findings, and technological trends related to illegal dumping and GIS applications. Literature was gathered through Google Scholar, Scopus, and Web of Science using search terms such as 'illegal dumping', 'GIS', 'informal settlements', and 'South Africa'. Sources published between 2000 and 2024 were included. Studies focusing on municipal waste services, GIS-enabled monitoring, legislative frameworks, and waste-management challenges in developing countries were prioritised, while engineering-focused landfill design papers were excluded. This approach allows the integration of empirical evidence, municipal case studies, and conceptual analyses into a coherent synthesis relevant to South African waste-management realities.

2. The Emergence of Informal Settlements in Developing Countries

Informal (settlement) development is a dominant trend of urbanization in many developing countries, especially on agricultural land, private land and public space that lack public services (Fernandes, 2011; Menshawy and Salman, 2011). According to Msimang (2017); Ono and Kidoroko (2020), people continuously migrate to the cities in search of better opportunities to sustain livelihoods and ultimately the number of informal settlements increases, hence resulting in many and complex socio-economic and environmental consequences. Like many other countries globally, this has been observed in Kenya and Brazil. Thus, informal settlements are considered a threat to the sustainability and development of many countries. Ono and Kidoroko (2020) revealed that Africa is one of the most rapidly urbanizing continents in the world.

The majority of African people are residing in townships that are characterised with informal settlements that lack basic services. The emergence of informal settlements in most cities is distinct evidence of the powerful political influence that was governing in the past. This led to the degradation of natural resources, urbanization, and most importantly the change of the social systems of living that has segregated people according to difference socio-economic status (Myers, 2003).

Kenney (2011), Jiusto (2011), Chikoto (2009) and Mels et al. (2009) have recognized this in South Africa and corroborated that dating back to 1949, the apartheid era intensified a long period of discrimination against blacks, Indians and coloured people; creating the tensions of segregation and the challenges of social inclusion and environmental security. Thus, the upgrading of informal settlements has been complicated by the apartheid era even after apartheid was finally lifted in 1994. This is mainly because the apartheid spatial planning has not been reversed through spatial development framework. Kenney (2011) reveal that the lack of basic services has led to many problems in informal settlements, such as social well-being, environmental and economic issues within settlements. Since 1994, the government struggled to achieve a permanent solution to these problems even after the constitution was promulgated in 1996 in an effort to ensure better service delivery to all citizens (Muller, 2008). Still, the process of putting the concerns of the informal settlements at the forefront remains a complicated task.

3. The Challenges of Basic Services in the Informal Settlements

Impoverishment and lack of basic services are some of the factors that contribute to the existence of informal

settlements (Simiyu et al., 2018). These conditions are often exacerbated by the lack of resources and the insecurity of the residents. While basic services are usually provided by the government and are generally related to the areas of water, sanitation, electricity, and waste management. (Msimang, 2017). Waste management services are one of the most observed indicators that impact the informal settlement dwellers in both the developing and developed countries and such can be drawn as a global challenge (Williams et al., 2019). A study by Simiyu et al., (2018) in Kisumu, one of Kenya's informal settlements concluded that the lack of basic services in these settlements is a reflection of poor enforcement of policies. While Fernandes (2011) and Msimang (2017) assert that informal settlements are unplanned and unstructured which paves a way for the inability of basic service provision.

Tembon, (2012) noted that among waste management services in informal settlements, there's a lack of waste collection services. This is because of numerous factors that contribute to the lack of road access in many informal settlements. These include the lack of cooperation from the residents and inadequate financial means. This implies that waste collection trucks have no access to informal settlements making it challenging to collect waste. An example of this is observed in confronting informal settlements of Ghana at Accra and South Africa (Antwi, 2008). According to Chikoto, (2009); Ngeleka (2010); Makabeni, (2018) many informal settlements in South Africa including Kliptown in Soweto, Claremont in KwaZulu-Natal and Dunoon in Cape Town all have common waste management challenges. These include inadequate sewage disposal facilities, poor roads, and accumulation of solid waste by the skips. Furthermore, large volumes of refuse are left to litter the streets and accumulate in open dumps where flies, rats, rodents, and other disease-carrying insects' breed. Selani (2017), have also demonstrated that the informal neighbourhoods are faced with inadequate or lack of waste removal, which reflects patterns of social isolation and ultimately threatens the health of the public and the environment.

4. Waste Management Legislation in South Africa

Incorrect disposal of waste is covered at all three levels of government (national, provincial, and local) legislation and regulations in South Africa. Relevant sections of the spheres of government legislation and regulations are well documented in the constitution of South Africa Act 108 of 1996; National Environmental Management Act (NEMA) 107 of 1998, and the National Environmental Management: Waste Act 59 of 2008 (Abel, 2014). Zhakata et al., (2016) also assert that the enactment of the constitution enshrines democracy and human rights which are essential to making sure that everyone's interests and needs are addressed. Such needs include

waste management service delivery. Thus, as a supreme or higher law, its provisions provide a framework under which all regulations, legislation, institutions, and procedures operate effectively and efficiently.

Buso et al., (2015) and Nkosi (2015) adds that the constitution is at the centre of the political and social life of the country. It defines the relationship between the State and the society, and between the distinct functions of the State. Thus, each organ of state must ensure that the provision of services to communities are rendered in a suitable manner that provides a safe and healthy environment. Grangxabe et al. (2023) highlight that one of the most important purposes of the constitution is the bill of rights that guaranteed certain basic rights for its citizens. One of the basic rights stipulated in section 24 of the bill of rights is the right to a healthy and protected environment for the benefit of the present and future generations. It is however noted that a vast majority of South Africans in informal settlements live in environments that are harmful to their health and wellbeing, although albeit the purpose of the NEMA (Act No. 107, 1998: 1) provides for the establishment of principals in decision making in all matters that relate to environmental issues; institutions that will promote cooperation in the governance and the environmental functions of state organs and; enforcement and administration of environmental management laws and related matters. is to "*provide for co-operative environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that will promote co-operative governance and procedures for co-ordinating environmental functions exercised by organs of state; provide for certain aspects of the administration and enforcement of other environmental management laws, and provide for matters connected therewith*."

Therefore, National Environmental Management: Waste Act 59 of 2008 must equitably prioritise people and their needs by ensuring that the state efficiently tackles the challenges of pollution and unsustainability in informal settlements. Moreover, waste disposal is critical during the waste management processes of various municipalities, hence the need for more proactive governance and technological intervention regarding waste management (Zhakata et al., 2016).

According to the Department of Environmental Affairs (2013); Kidd (2011) and Zhakata et al., (2016), *"waste management is one of the critical elements of sustainable development primarily because sound waste management practices contribute to sustainability."* Conversely, Zhakata et al., (2016) argues that legislation regulating waste management legislation in South Africa has historically been fragmented and still is, to some extent. Kotzé, (2005) explains that this is because the line functions of the national, provincial, and local spheres work independently from one another, and governance across the spherical divides is also largely discontinuous. Ultimately, prevents the achievement of sustainable

service delivery. On the contrary, Kidd, (2011) describe that the coming into effect of the National Environmental Management: Waste Act (Act No. 59 of 2008) (NEM: WA), presents more holistic approaches to waste management regulation. This holistic approach is aimed at addressing aspects of waste management, which includes the unavailability of information relating to legal and illegal dumping sites. Substantial portions of the population are not receiving frequent and adequate waste collection service. The lack of these databases promotes inadequate regulation and enforcement of the legislation (DEA, 2011). Although the waste act is in place, most municipalities still find it challenging to efficiently implement waste management strategies (Kidd, 2011; Zhakata et al., 2016). Recent empirical work by Ntlangula, Xelelo and Chitongo (2025) further highlights these enforcement gaps, showing that illegal dumping persists largely because monitoring capacity is weak, enforcement is inconsistent across income groups, and municipalities lack sufficient resources to ensure compliance. Informal settlements often experience inadequate waste collection services, poor infrastructure and inconsistent municipal support, patterns also observed in other developing regions where irregular collection and uncontrolled dumping are common (Argun et al., 2015).

When viewed comparatively, South Africa's waste-management landscape reflects patterns observed across several developing regions, where legislation is well-established but implementation remains inconsistent. In contrast, countries such as Japan, Germany, and the United Kingdom maintain strict enforcement mechanisms, high collection frequencies, and advanced separation-at-source systems supported by strong institutional capacity. Similarly, many Latin American cities—such as São Paulo and Bogotá—demonstrate more structured integration of community recycling programmes and municipal monitoring tools. The divergence highlights that South Africa's challenges are not rooted in the absence of policy but in infrastructural inequalities, service-delivery fragmentation between formal and informal settlements, and limited technological adoption. This comparative perspective clarifies the structural drivers behind illegal dumping and underscores the need for integrated, multi-level governance reforms.

Consequently, to address the waste management challenges and realise the objectives of the NEM: WA, the DEA published the NWMS in 2012 in order to support the goals and objectives of the NEM: Waste Act. Furthermore, to the extent that the NWMS creates norms and set standards at the national, provincial and local spheres (Alberts, 2014), it encourages municipalities to include their Integrated Waste Management Plan's (IWMP) in their respective Integrated Development Plan's (IDP) for waste management services to be streamlined along with other basic services such as water, sanitation, electricity and housing (Zhakata et al., 2016). Table 1 shows the existing waste management methods that are commendable but have not yet delivered the needed impact due to lack of proper execution, flexible approach, and weak technical enforcement. Although the objectives of the NEM: WA demand the desired sound waste management, the reality at present looks different because challenges with waste infrastructure and delivery of waste services and the problem of litter and illegal dumping are still visible. Therefore, there is an urgent need to adopt flexible approaches that promote better service delivery for communities.

5. Current Existing Practices of Managing Waste in Informal Settlement

Waste management involves generation, collection, handling, transfer, disposal, reuse, and recycling (Noiki et al., 2021; Demirbas, 2011; DEA, 2011; Dri et al., 2018). Waste management practices differ from one country to another depending on the waste sources, types, policies, regulations, and laws (Noiki et al., 2021; Coker, 2016). Numerous studies by Noiki et al., (2021); Ike et al., (2018); Agwu, (2012) and McAllister, (2015) identified that current waste management practices around the world are fast becoming unsustainable and leading to notable environmental risk; particularly in informal settlement. This is observed in the United States of America (USA), Japan, Zimbabwe, Kenya and including South Africa (United States Environmental Protection Agency, 2015; Stephen, 2014; Bhagwandin, 2013; Jerie and Tevera, 2014; Gutberlet et al., 2017; Mwangi et al., 2021 and Haywood et al., 2021).

According to the United States Environmental Protection Agency, (2015) and Chisadza (2015), the USA produces huge volumes of waste, Also Stephen, (2014) and Jakeni et al. (2024) identified that Japan generates waste worth approximately 50 million tons annually. Further that, Japan is faced with many challenges of illegally dumped waste. However, its government have implemented the reduction, reuse, recycling, and recovery method to manage the issue of illegal dumping. Bhagwandin, (2013) and Chisadza (2015), observed that in the USA, Australia, Canada and England waste is properly managed and stored in bags and transferred in large steel or plastic bins which are lifted mechanically by the compactor trucks to the waste transfer facilities. Nevertheless, Refsgaard and Magnussen, (2008) and Jakeni et al. (2024) assert that developed countries have advanced technology used for proper handling and management of waste. Thus, Sthiannopkao and Wong (2013) indicate that despite the copious amounts of waste produced in developed countries; its technology has progressed in terms of handling, storing, collecting, and transporting waste to the final destination that promotes sustainable environment.

Table 1. Enforcement strategies for effective compliance with NEM: WA.

Enforcement strategies for effective compliance with NEM: WA	Aim
National Waste Management Strategy	• The framework of eight goals, to understand the direction that waste management will take in the local government sphere. • Improve governance and enhance the effectiveness of public sector organisations and institutions. • Implements the Waste hierarchy. • Meets the social and environmental needs of the poor communities. • Runs awareness programmes in schools and municipalities about littering and illegal dumping.
Waste management norms and standards	• Requires that municipalities must exercise their executive authority to: i) deliver local waste management services. ii) perform their duties concerning waste services including i.e. waste collection.
Integrated Waste Management Plan & Integrated Development Plan	• Critical tools for achieving the objectives of the NWMS to: i) minimise the associated environmental impacts and financial costs associated with improper waste management. ii) provide for the negative impact of poor waste management practices on health and the environment within the area of jurisdiction of the municipality. iii) assist municipalities to set local standards for control of litter. iv) help with the implementation of the waste management hierarchy at a local level. v) Discuss issues of fiscal management and resource availability.
City of Cape Town Metropolitan Municipality By-Laws and Enforcement	• Deals with a variety of waste management service issues, including, i.e. collection of waste, types of waste collected, methods for waste collection, waste containers used and the frequency of waste collection. • Ensures that waste management services are appropriately budgeted for and provided sustainably and efficiently. • Monitor the compliance within waste service providers and generators. • Expanded Public Works Programme for cleaning of the illegally dumped material. • Appoints law enforcement officer to patrol for illegal dumping.

While Gutberlet et al., (2017); Mwangi et al., (2021) and Omollo, (2019) state that the waste situation in Kenya's informal settlement depend on individual waste pickers, recycling groups and community-based organisations. This is because waste is mainly collected in the central business district and the main markets. Thus, waste generated in informal settlement remains uncollected and illegally dumped in vacant spaces and along the road, leading to appalling conditions in the neighbourhoods. Jerie and Tevera (2014) also noted that Zimbabwe is also contending with the same problem of waste that is collected daily in the city centre and markets but only collected once in the residential areas. Whilst there is little to no adequate removal of waste in informal settlement. This results to the residents dumping their waste illegally and practice open burning in uncontrolled environments.

Likewise, South Africa is no exception to this. Haywood et al., (2021) and Naidoo (2009) reveal that it is the duty of government municipalities to implement effective waste management services. Furthermore, various levels of service delivery are recognized in South African national waste collection standards, depending on the practicality

and cost efficiency in each area (DEA, 2011). Hence waste removal frequencies are put in place to avoid environmental and health risks. Haywood et al., (2021) suggest that "*containers must be removed within 24 hours of being reported full but at least once a week*". Despite this, low-income area remains with waste uncollected and piled up along the roads, resulting to extensive littering and illegal dumping. A meta-analysis by Maphanga, Grangxabe and Madonsela (2025) reinforces this finding, demonstrating that informal settlements across South Africa consistently experience high waste-generation rates but extremely low collection coverage, reflecting systemic service-delivery inequalities that directly contribute to illegal dumping. Deficiencies in collection performance have been shown to accelerate environmental degradation, particularly in low-income neighborhoods, across different geographic contexts (Bayram et al., 2015; Bayram et al., 2019).

Literature has shown that within the City of Johannesburg, the majority of households have weekly waste collection, while the rest have less frequent collections (Chisadza, 2015; Rasmeni and Madyira, 2019). Furthermore, the current existing waste

management practices are done using curb side collection and collection points such as waste skips. In addition to the principal methods currently used, there are cleaning programmes such as 'Pikitup' designed for informal settlements to clean illegally dumped waste but are costly and inadequate. According to the Integrated Development Plan (IDP) of the City of Cape Town, the collection of waste in formal households is done on a weekly basis. While informal settlements receive a door-to-door collection and frequent cleaning services within the area.

However, Armitage et al., (2010) noted that majority of informal settlements in Philippi, Khayelitsha and Kosovo still experience waste overflows from waste skip that has not been collected for a long time. Van Oordt (2018) state that the cleaning services offered in the informal settlements to combat illegal dumping costs the City of Cape Town millions of rands, but illegal dumping still continues despite the financial costs, stringent penalties and the law enforcement in place. According to Viljoen et al., (2021) state that the Hantam municipality in the Northern Cape follows the onsite, offsite and curb side waste disposal practices to manage waste. However, the mostly used method is burning and litter and/or dumping in open spaces. The municipality implemented the plastic bag system for the removal of waste, but it is often not provided for the residents. Furthermore, the drop off points for collection are far and the residents are not willing to travel further thus opt for dropping the waste on open spaces. Viljoen et al., (2021) and Serret and Ferrara (2008) emphasise that the distance between the houses and waste collection points has a major negative impact on waste management. Consequently, Wang et al., (2018) suggest that multiple collection points close to houses plays a significant role for proper waste management practices. While Viljoen et al., (2021) further recommends that exploring different and innovative alternatives such as to "*locate, map and monitor uncontrolled dumpsite*" using advanced technology can help to combat the issue of illegal dumping.

A series of recent studies by Thompson et al., (2013); Shaikh, (2006); Zhu et al., (2007); Agarwal, Chaudhary, and Singh, (2015) has indicated that the current existing waste management system uses a manual way for record keeping, allocation of collection services and monitoring of waste. Each area under the jurisdiction of its local municipality is assigned waste collection days and waste depots that are a certain distance from the area. Furthermore, the waste collection vehicle starts at a designated time two-three times a week for its waste collection trip. The collection of waste is not done with an intent of fulfilling the means of the NEM: WA and the bill of rights; such that there are no improvements with the waste management issues even though there are measures and tools in place to alleviate waste issues. This has also been explored in prior studies by Abel (2014), Nkosi (2015) and Bhattacharjee and Polas, (2018) in the

case of South Africa. Nonetheless, there are several systematic approaches in the system but fall short of a comprehensive plan.

6. The evolution of GIS and its Adoption

The Geographic Information System (GIS) can be defined as a tool and/or system for capturing, storing, manipulating, analyzing, managing, and displaying spatial data (Scholten and Lepper, 1991; Pandey et al., 2013; Thompson et al., 2013; Amakihe, 2011; Jimoh et al., 2019). The GIS phenomenon was founded in the 1960s by Roger Tomlinson and was later explored as an advanced discipline (Goodchild, 2018; Tate, 2018; Maguire, 1991). According to Martí-Henneberg (2011), the first GIS data on land usage was collected and analyzed with an effort to manage the country's resources in Canada. Furthermore, by the 1970s to 1980s the concept of GIS evolved as many entities as possible in the industry saw its potential and was continuously integrated and commercialised with satellite imaging technology (Deakin, 2009 and Tate, 2018). Consequently, by the late 1980s, the focus on improving the usability of technologies as a single path finally emerged. Fazal (2008) and Amakihe (2011) agree, that GIS use was associated with static data, a long time and involved only a few specialized users. However, in the 1990s, a software company Environmental Systems Research Institute (ESRI) released ArcView, a desktop solution for mapping systems. Today, GIS can be used in a short amount of time to process data in a simple form that can be interpreted easily and still maintain the integrity of information processed. Thus, GIS offers spatial functions that aid in solving complex problems. Thus, the visualization of GIS data through the internet on google maps, google earth, and open street map has become widespread (Henry, 2009; Martí-Henneberg, 2011; Arsanjani et al., 2015). Thus, the adoption of GIS is heading into the millennium, and the technology has now reached private entities and governmental authorities for planning and decision making in various fields (Tate, 2018; Amakihe, 2011; Fazal, 2008).

7. From Traditional Waste Management To Integrated Waste Management

Historically, the waste management approach in South Africa and elsewhere has narrowly focussed on the collection, transportation, disposal and treatment of waste from a public health and service delivery perspective (Davies, 2009:159). As Davies (2009:159) notes, "this waste management's paradigm was dominated by local government legislative or policy framework with a myopic focus on collecting and disposing of waste without addressing waste from the source." According to Marshall, and Farahbakhsh (2013) this type of waste management was informed by an escalation of products in the modern economy that further induced waste generation particularly in urban

areas. It is thus from this background that a greater need for a more organised waste management system, based on modern engineering and technical administration is required to ameliorate environmental and health problems emanating from littering, indiscriminate dumping of waste in the municipal public open spaces. This type of waste management system was characterised by high bureaucracy and technical inputs with little involvement of local communities.

The top-down and technical approach to waste management came with a number of environmental, social and economic challenges. For instance, countries such as New Zealand were confronted with the cost and environmental effects associated with identifying suitable sites for waste disposal (Davis, 2009:159), a problem that has increasingly affected South Africa over the last 30 years. This is due to the fact that waste management in general and municipal waste management approach in particular, has not yet paid attention to addressing waste from the source (Ibid, 2009). With the advent of integrated or sustainable waste management concept, informed by the resurgence of sustainable development in the early 1990s, there is a need to explore how cutting-edge technologies such as GIS can be used to deal with waste management problems from the source. Historically, the waste management approach in South Africa and elsewhere has narrowly focussed on the collection, transportation,

disposal and treatment of waste from a public health and service delivery perspective (Davies, 2009:159). As Davies (2009:159) notes, "this waste management's paradigm was dominated by local government legislative or policy framework with a myopic focus on collecting and disposing of waste without addressing waste from the source." According to Marshall, and Farahbakhsh (2013) this type of waste management was informed by an escalation of products in the modern economy that further induced waste generation particularly in urban areas. It is thus from this background that a greater need for a more organised waste management system, based on modern engineering and technical administration is required to minimise waste management problems around informal settlements and public open space areas.

8. The Benefits of Using GIS

The main objective of GIS is to allow users to find answers to their questions and solve problems by presenting data in simple visual ways (Pandey et al., 2013). Thus, GIS optimizes the efficiency of decision making and planning, also providing efficient means for data distribution and handling while eliminating the duplication of data at the minimum cost (Pandey et al., 2013; Mlisa, 2007). The benefits of GIS can be classified into five categories as depicted by the table 2 below.

Table 2. Five categories of the benefits of GIS

Category	Description
Cost savings resulting from greater efficiency	Improves economic efficiency by increasing productivity i.e. labour savings and improving workflow (Fais, and Bonati, 1997; Pandey et al., 2013 and Martynova et al., 2019).
Better decision making	Deals with making better decisions about spatial relationship related to proximity, connectivity, and the overlay of methods. Spatial decision support systems (SDSS) are one of the GIS decisions making concept that allows information system technology to increase the effectiveness of decision makers (Mlisa, 2007).
Improved communication	Effective presentation of information through GIS-based maps and visualizations that assists in understanding and analysing problems and solutions across multiple disciplines (Pandey et al., 2013 and Martynova et al., 2019).
Better geographic information record-keeping	Organizes and stores valuable information and/or geographic data and make it accessible from anywhere, at any time (Pickering et al., 1993).
Managing geographically	Capable to select information by area or by theme and combine one data set with another, to analyse spatial characteristics of data, to search for particular features and monitoring of data (Jakeni et al., 2024).

9. The growth and development of GIS in South Africa

The role of GIS is increasing in developing countries due to ever increasing population growth, slow economic growth, depletion of natural resources, infrastructural planning, and service delivery (Mennecke and West, 2001). However, GIS is still limited in some parts of the African continent because of the challenges associated with the availability of updated data, sufficient data

storage and appropriate software (Sipe and Dale, 2003; Mennecke and West, 2001). The initial application of GIS in South Africa was discovered in the 1990s through the state institution; that is the "Chief Directorate Surveys and Mapping and the chief Surveyor General of South Africa" and is now noticeable growing in recent years.

The GIS technology is used by government departments, semi-private institutions, consulting entities and universities (Breetzke, et al., 2011; Das et al., 2010). Government departments such as the local municipalities

use GIS to address issues such as development planning, housing and infrastructure, disaster management, tourism, agriculture, and water resources management. According to Das et al. (2010), the City of Ekurhuleni municipality uses GIS to analyse and address the state of the province and its service delivery to the residents. While the City of Cape Town municipality implemented a geodatabase for electricity, property, and water services. It is important to highlight that even though many developments of GIS are taking place, it still remains limited and not optimally used in other sectors of concern such as waste management services. A comprehensive regional review by Shabani et al. (2024) similarly concludes that GIS and Remote Sensing applications in Southern Africa remain in their embryonic stage, constrained by limited datasets, insufficient technical capacity and financial barriers, which collectively hinder full integration into municipal waste-management systems.

Across international case studies, GIS adoption in developed countries is predominantly proactive—focusing on predictive optimisation, route planning, early detection of illegal dumping risks, and integrated decision-support systems. In contrast, developing countries tend to use GIS reactively, mainly for post-hoc identification of illegal dumping hotspots and basic mapping of waste accumulation. This divergence reflects differences in institutional capacity, data availability, and technological investment. The South African context aligns more closely with the latter, where GIS is available but applied in a limited, problem-responsive manner rather than as a strategic planning tool. This comparison underscores a key opportunity for South Africa to transition toward more preventive, data-driven waste-management practices.

10. The Contribution of GIS in Waste Management in Developing and Developed Countries

Waste management requires a lot of planning for the efficiency and effectiveness of proper waste disposal which is a crucial factor in waste management. Thus GIS offers a wide range of functions that can manipulate information concisely for a desired output such as planning transport routes and waste collection points (Wekisa and Majale, 2020; Kallel et al., 2016; Karadimas and Loumos, 2008), selection of areas suitable for waste disposal (Nishanth et al., 2010; Sivasankar and Rathinam, 2017; Karsauliya, 2013; Mohammedshum et al., 2014), locating new landfills and transfer stations (Kimwatu and Ndiritu, 2016; Basavarajappa et al., 2013), identifying potential illegal waste dumping areas (Zainun et al., 2016; Chu et al., 2013; Sule et al., 2014; Mihai et al., 2015; Jakiel et al., 2018; Tasaki et al., 2007; Seror and Portnov, 2018; Romeo et al., 2003; Jimoh et al., 2019; Glanville and Chang, 2015; Jagila et al., 2014; Kubásek, 2013). Also, GIS has the potential to monitor changes in the environment

such as climate, land use, environmental sensitives zones, population, and basic service delivery. Thus, GIS can add value to waste management by providing outputs for decision support, analyse and monitor waste management databases to improve waste management services while contributing towards sustainability of a country (Amakihe, 2011; Vaisgampayan, 2014).

11. Planning Transport Route and Collection Points

Waste collection is a crucial but most challenging stage in waste management system due to cost implications, capacity, and inaccessibility within areas (Wekisa and Majale, 2020). A series of recent studies (Malakahmad et al., 2014; Islam et al., 2016; Kallel et al., 2016) has indicated that the use of GIS application for collection and transport optimization can help with optimal usage of resources with low economic and environmental costs. The aforementioned studies were conducted in Tunisia, Malaysia and Bangladesh, following the ArcGIS network analyst method to improve the collection points and transportation of waste (Malakahmad et al., 2014; Islam et al., 2016; Kallel et al., 2016). The ArcGIS network analyst method optimizes the operation of existing systems and develops advanced techniques to design and evaluate new systems for proper route for collection (Malakahmad et al., 2014). The aim of the network analyst was to determine the time taken to drive from one route to another and the collection time taken for each route to achieve reduced collection time and the route selection that is more optimum. The studies concluded by asserting that the use of ArcGIS network analyst for the route optimization has shown reasonable improvement in length of the routes and travel time minimization. Similar GIS-based optimisation approaches have been successfully applied outside Africa as well. For example, Argun and Bilgin (2025) demonstrated that route optimisation aligned with zero-waste principles significantly reduced operational distance and fuel consumption in Türkiye, suggesting that comparable models could be adapted within South African municipalities facing logistical constraints.

While a promising method, the GIS algorithm has been discussed by Karadimas and Loumos, (2008) and Vijay et al., (2008) to facilitate with identifying the location and allocation of waste bins and finally support the transport route for waste collection. The significance of the GIS algorithm allows the triangulated irregular network model that provides flexibility to conduct a criterion of a down and upslope movement in relation to road network, the distance between the bin location and household (Shaikh, 2006). Thus, the criteria ensure proper location of bin that is easily accessible to each household and ease in transportation to collect waste. This was observed in Greece and India (Karadimas and Loumos, 2008; Vijay et al., 2008). Both above highlighted methods are intended to achieve economic and

environmental benefits; thus, travel time, distance, fuel consumption and pollutant emission reduced compared to the outcomes of the current existing used methods.

12. Selection of a Suitable Waste Disposal Landfill Site for Disposal of Waste

According to Nishanth et al., (2010) and Mandizvidza et al., (2020) waste that is collected, not recycled, or reused usually ends up at a landfill site. Mandizvidza et al., (2020); Kimwatu and Ndiritu (2016) noted that the final disposal of waste to a landfill site is a common method that is widely used in many countries. However, sin et al., (2016) note that the landfill sites have become unsustainable and have reached it carrying capacity of waste. Nishanth et al., (2010) and Basavarajappa et al., (2013) reveal that because of the above-mentioned reasons it has become a serious challenging task to find a suitable landfill site due to social and environmental parameters. As a result, sufficient geospatial data is needed. Literature shows the success implementation of GIS integrated with remote sensing techniques. This model used a multi-criteria evaluation method for site selection; this was observed in Ethiopia, India, Kenya, and Iraq (Nishanth et al., 2010; Sivasankar and Rathinam, 2017; Karsauliya, 2013; Mohammedshum et al., 2014; Kimwatu and Ndiritu, 2016; Basavarajappa et al., 2013; Mussa and Suryabhagavan, 2021).

In addition, Kimwatu and Ndiritu (2016) explain that the use of GIS and remote sensing can integrate numerous factors that involves decision making for a suitable site selection. Mohammedshum et al., (2014) also adds that the combination of GIS and remote sensing have a significant importance for selection of a suitable landfill site because of both its advantages that are effective in solving problems. Consequently, the multi criteria evaluation method considers the proximity analysis in relation to road, settlement location, drainage network, land use and sensitivity of the area to come up with concrete results that can be classified as a high suitable area for the disposal of waste. Thus, Kimwatu and Ndiritu, (2016) state that landfill should not be situated in a vicinity where there are public transportation routes but must be located at a suitable distance from road network however still be able to facilitate the transportation of waste and reduce relative cost involved.

13. Mapping Illegal Dump Sites Using GIS Techniques

Several methods are reported in the literature to address the issue of illegal dumping and among those is the implementation of GIS that has shown success in helping to combat illegal dumping around the world. The use of GIS to can be drawn from a study conducted by Jagila et al., (2014) at Minna in Nigeria; through the use of Geospatial technology to analyse the spatial patterns of waste dump sites and the health hazards associated with the observed pattern. The study adopted a proximity analysis model to determine the distance from the dumpsites to roads, rivers, and the built-up areas. Furthermore, the study concluded that the Geospatial technology helped in providing information system. The purpose of the model was to establish a system that will provide information about dumping sites in various districts, and to help with monitoring and management of these sites which eventually prevents environmental hazards and disease outbreaks. The selected model by the study sought for a site suitability for a waste segregation facility so that waste can be recycled thus to help with waste minimisations and sustain landfill space which is a genuine issue across the world.

Likewise, Jakiel et al., (2019) demonstrated that the spatial distribution of illegal dumping can help with understanding the variations on the environment. Thus, factors the management and monitoring system of illegal dumping. The study focused on determining the spatial and temporal changes of illegal dumping sites in one of the national parks in Poland using GIS for mapping. The study established that the distance from the roads and the field forest edge are the most crucial factors that control the distribution of illegal dumping. Jakiel et al., (2019) concluded by asserting that the outcome of the map produced reveal the sites and places that need special focus in avoiding further occurrences thus to help local authorities for better management. In addition, Glanville, and Chang (2015) also reported the importance of using GIS to assess the distribution of illegal waste disposal sites and ultimately map and monitor illegal waste disposal sites in Queensland, Australia. The study explored a GIS mixed approach in addressing a critical gap in the detection of illegal waste disposal sites.

While Tasaki et al., (2007) suggest that the focus should not be on the occurrence of illegal dumping but on the size of illegal dumping and that can be determined by the use of zoning to assist in the efficient surveillance against illegal dumping. Thus, the evaluation of zoning results reveals sites that have a higher potential for large illegal dumping, and this was implemented in Japan and yielded successful results since illegal dumping is often managed by cleaning it up. Romeo, Brown, and Stuver, (2003) argue and demonstrate that one of the crucial factors to consider when dealing with the issue of illegal dumping using GIS is to develop a model to predict the susceptibility of illegal dumping to informal settlements. This was implemented in Texas using a model builder utility of the ArcView spatial analyst extension. The model revealed that visibility, accessibility, and density are identifying key features that impact illegal dumping location choice. Thus, areas in close proximity to roads are likely to dump waste along roadside because of easy access.

Conversely Kubásek, (2013) state that GIS can be utilised on a mobile device. This was observed in the Czech Republic to report illegal dumping and overloaded municipal waste containers which contribute to reduce

environmental pollution. The mobile based application encourages the citizens to create a map of illegal dumpsites in their surroundings. As a result, the application allows both the community and the municipality to work together since the application is effective as a widespread platform for reporting and monitoring illegal dumping (Kubásek, 2013).

14. Limitations and Future Research Directions

This review is limited by its reliance on secondary literature and the lack of systematically collected municipal datasets on illegal dumping and GIS use. In addition, empirical assessments of GIS implementation in informal settlements remain scarce, making it difficult to evaluate the real-world effectiveness of proposed technological interventions.

Future research should include municipality-level empirical studies, evaluations of citizen-generated spatial reporting tools, and pilot testing of cost-effective GIS models tailored to resource-constrained settlements. Further work is also needed to strengthen datasets for illegal dumping hotspots, develop predictive modelling frameworks, and assess how institutional capacity shapes GIS adoption across municipalities.

15. Conclusion

Waste management across the world is a dynamic process in terms of collection and disposal. The scope of waste management differs in each country. In South Africa, it is the responsibility of the local municipality to ensure that services are rendered to its communities; however, the reality currently looks different because waste collection services are insufficient, resulting in waste piling up next to bins and people disposing of waste illegally, resulting in waste scattered throughout vacant spaces despite legislation mandating proper waste management. Literature shows that waste management in developed countries has improved from its current state. The evolution is backed by the adoption of the advanced technology such as GIS to address waste related problems. Even though GIS is still limited in some parts of the developing countries including South Africa, it has proven to yield positive results in helping to deal with waste issues more particularly with illegal dumping. An appropriate use of available technological advances within the financial means of the country and municipalities can provide the right solutions in waste management. Thus, increasing efficient collection mechanism, monitoring of illegal dumping and proper service delivery. Policy actions should prioritise the establishment of integrated geodatabases for mapping formal and informal waste flows, expansion of community-level reporting tools, and routine GIS-based monitoring of illegal dumping hotspots. Future research should evaluate cost-effective GIS models tailored to resource-constrained municipalities, assess citizen-

generated spatial data for monitoring, and test proactive GIS-enabled routing systems against conventional waste-collection practices. This review is limited by its reliance on secondary literature and the lack of systematically collected municipal datasets on illegal dumping and GIS use.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	X.S.G.	M.K.	T.M.	B.S.M
C	20	40	20	20
D	20	40	20	20
S	20	40	20	20
DCP	20	40	20	20
DAI	20	40	20	20
L	20	40	20	20
W	20	40	20	20
CR	20	40	20	20
SR	20	40	20	20

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declare that there is no conflict of interest.

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