# A GEOGRAPHICAL ANALYSIS OF THE IMPACTS OF CONSTRUCTION AND DEMOLITION WASTE ON WETLAND FUNCTIONALITY IN SOUTH AFRICA: A STUDY OF GAUTENG PROVINCE.


BY

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**Ethics Clearance Number: H22/07/19**

September 2024.

## DECLARATION 1-PLAGIARISM

I, Ngonidzashe Mangoro, declare that this thesis, figures, and tables therein are my original work except where it is acknowledged. Additionally, this thesis does not contain another person's contribution except where it is stated otherwise.

In those scenarios where other sources are referenced, their work is paraphrased, and the general concept or data is credited to them following the rules of ethical scholarly studies. Additionally, direct quotation marks were deployed in areas where exact words were used, and the work was attributed to the author/ authors.

This thesis is being submitted as part fulfilment of the requirements for the degree of Doctor of Philosophy in Geography and Environmental Studies to the Faculty of Science at the University of the Witwatersrand, Johannesburg, South Africa. It has not previously been submitted for examination or award of degree to any other institution of learning anywhere in the world.

## DECLARATION 2-PUBLICATIONS

I, Ngonidzashe Mangoro, hereby declare that the manuscripts mentioned below are informed by literature and data collected and analysed by myself throughout my doctoral study at the University of the Witwatersrand. In addition to data collection and analysis, the write-up, submission, and resubmission to journals were undertaken by me. However, I wish to credit my co-authors for providing critical advice, adding text and comments, and editing the manuscripts to make them publishable in credible journals. Finally, sections of this work have been published or submitted as manuscripts for publication to the following peer-reviewed journals:

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Signature: Date: September 2024

As the candidate's supervisor, I certify the above statement and have approved this thesis for submission. I certify that the above statement is correct:

Signature: Professor Mulala, Danny Simatele Date: September 2024

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## EXECUTIVE SUMMARY

The purpose of this study was to investigate construction and demolition waste management processes in sub-Saharan Africa and how they affect wetland ecosystems, using South Africa as a case study. Construction and demolition (CDW) waste has become a massive urban environmental challenge on a global scale, but more so in developing countries found in sub-Saharan Africa. In the context of South Africa, construction and demolition waste is not a waste stream taken seriously by local and national authorities because it is 'general waste' that does not pose an immediate threat to the environment. This position is premised on the idea that construction and demolition waste is generally inert (chemically inactive) and therefore cannot cause an immediate environmental risk. In this study, it is argued that the environmental risk of waste goes beyond the embedded chemical constituencies because some waste streams can cause immediate environmental risk through their physical properties depending on the location of disposal. It is further argued that although CDW is generally inert, disposal in wetlands immediately disrupts the way wetland ecosystem's function, causing several environmental risks. To mitigate the environmental threats posed by construction and demolition waste, this study proposes a change in the methodological approaches and strategies deployed to manage the waste stream, such as by introducing a hybrid of circular economy and industrial ecology to minimize or eliminate waste production.

This study involved several data collection and analysis methods. Using a combination of qualitative and quantitative studies methods, data was collected with the goal to understand the perceptions of experts on how construction and demolition waste management in South Africa affects wetland ecosystems and what can be done to effectively manage the waste stream in the context of a developing country. Data informing this study were collected through semi-structured interviews and surveys in the province of Gauteng, specifically in the City of Johannesburg and City of Ekurhuleni Municipalities, where there is massive illegal dumping in wetlands for various reasons. Furthermore, apart from the use of semi-structured interviews and surveys, a digital elevation model was generated in ArcGIS Pro 10.1 software to measure the effects of construction and demolition waste on wetlands in

the study area. The approach to this study using both qualitative and quantitative methods was crucial because it provided human perceptions which were accurately corroborated by GIS software.

The study found that construction and demolition waste management in South Africa is affected by several challenges that lead to massive illegal dumping in critical ecological ecosystems such as wetlands. In a broad sense, the major challenge to sustainable construction and demolition waste management in South Africa is institutional failure at both the local and national levels. Local authorities such as municipalities are characterized by massive corruption, poor funding, and lack of strategic technologies among other things, while at the national level, there is massive interference with municipal affairs through bureaucratic delays in the disbursement of municipal funds. A combination of these and other factors leads to illegal dumping of construction and demolition waste across the Gauteng Province, particularly in wetlands in low-income areas. The data informing this study reveals that dumping construction and demolition waste in wetlands causes an immediate threat to the existence of wetlands through massive sedimentation with insoluble materials. It is ultimately found that construction and demolition waste destroy the ability of wetlands to offer ecosystem services such as flood attenuation, carbon sequestration, water filtration, and habitat provision, among other functions, leading to environmental events such as flooding.

A combination of circular economy and industrial ecology can be one of the ways that can be deployed to effectively and sustainably manage construction and demolition waste in South Africa. The circular economy and its three principles of 'reduce', 'recycle', and 'reuse' has been successfully deployed in developed countries in the European Union, where recycling has topped 70% of the total construction waste generated. Industrial ecology with its analogy of industrial ecoparks has been deployed in the European Union with immense success, until more attention was directed to circular economy. With an increase in municipal funding and introduction of a construction waste information system, a combination of 'circular economy' and 'industrial ecology' can significantly help to reduce pressure on wetlands and the environment at large.

Even though the methodological improvements suggested above could significantly reduce pressure on wetlands, the implementation could be faced with institutional challenges. Therefore, it is argued that urgent institutional transformation is required to make tangible changes in the field of construction and demolition waste management. It is recommended that there should be increased law enforcement to curb widespread illegal dumping in South Africa's major cities. It is also recommended that, like in Europe, South Africa must introduce tailor-made legislation of policies for construction and demolition waste alone. Promulgation of dedicated legislation provides clear direction on how the waste stream is managed and who is responsible for specific roles. Furthermore, dedicated legislation can be a crucial tool to deliver sustainable construction and demolition waste management in South Africa because it can be used to encourage the use of recycled aggregates and limit the amount of illegal dumping or extraction of materials from the environment. Finally, dedicated construction and demolition waste legislation can be used to shift from the traditional view of pollution or contamination through toxicity, and so the value of this study is immediately apparent.

***Key Words:*** *Construction and demolition waste, wetlands, environment, circular economy, industrial ecology, solid waste management, more-than-human theory.*

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## LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| BIM | Building Information Modelling |
| CDW | Construction and Demolition Waste |
| CE | Circular Economy |
| DEA | Department of Environmental Affairs |
| DEM | Digital Elevation Model |
| DfD | Design for Deconstruction |
| EMI | Environmental Management Instrument |
| EPA | Environmental Protection Agency |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| ICT | Information Communication Technology |
| IE | Industrial Ecology |
| KSA | Kingdom of Saudi Arabia |
| LULCC | Land Use and Land Cover Change |
| NGO | Non-Governmental Organisation |
| OPAC | Online Public Access Catalogue |
| SANBI | South African National Biodiversity Institute |
| SR | Social Responsibility |
| SSA | Sub-Saharan Africa |
| SWM | Solid Waste Management |
| UAE | United Arab Emirates |
| UNEP | United Nations Environmental Program |
| UNICEF | United Nations Children’s Fund |

# CHAPTER ONE

# FRAMES OF REFERENCE

## 1.1. Background to the study

The world is overflowing with waste from the construction sector, which has expanded rapidly in recent decades (European Commission, 2015; Spisakova et al., 2021; Fitchett & Rambuwani, 2022). Construction and demolition waste (CDW) is heterogeneous liquid and solid matter that emerges from the construction, demolition, or renovation of various components of the built environment such as buildings, roads, pavements, industrial plants, etc., and through other civil engineering processes (Ponnada & Kameswari, 2015; Diotti et al., 2020). However, it is imperative to note that CDW is ontologically complex. Its provenance can also be attributed to natural phenomena such as earthquakes and tsunamis (Teresa et al., 2020; Coni & Madi, 2021), and other destructive anthropogenic activities like war (Assche & Gruezmacher, 2023). Examples to illustrate this can be drawn from the 2023 earthquake in Türkiye, which led to the simultaneous and instantaneous destruction of over 56,080 buildings across 10 provinces, including high-rise buildings, houses, roads, and bridges (Support-to-Life, 2023). Similarly, armed conflicts and their destructive tendencies have contributed immensely to the ruination of Ukrainian cities and towns, generating vast quantities of demolition waste (UNICEF, 2023; World Health Organization, 2023). Despite the different sources, CDW routinely comprises elements such as concrete, bricks, tiles, ceramic wares, wood, glass, plastic materials, asphaltic blends, coal tar, gypsum, and many other types of matter used in construction (Ponadu & Kameswari, 2015; Iacoboaea et al., 2019).

The heterogeneity of CDW hints at the notion that it presents a variety of negative environmental effects if it is not handled according to environmental best practices, especially because of its innate chemical properties (e.g. Global Health and Safety Initiative, 2008; Pacheco-Torgal & Jalali, 2011; Ismail et al., 2023). For example, recent studies established that potentially toxic elements (PTE) of cementitious material can contaminate the topsoil and crops over time (Ismail et al., 2023). Similarly, studies by Wahlstrom et al. (2019) found that polychlorinated biphenyls (PCBs) found in some construction materials can linger in the environment for extended periods, and cause among other things, soil, and water pollution. Contrary to these important findings, several scholars advance the notion that the bulk of CDW is generally inert (chemically inactive), and therefore it presents little environmental threat (e.g., Suman, 2020; Wang & Xi, 2020; Peng et al., 2022). This view of CDW and its materiality emerges from the deployment of conservative methodological approaches to environmental studies that traditionally measure the environmental performance of materials through the lens of their inherent chemicals and leachability in different contexts, such as water or dry earth. Ultimately, this approach has massive environmental ramifications because many governments and private operators around the world legally permit disposal of CDW in designated landfills, encouraged by the view that it poses an insignificant environmental threat (SA National Environmental Management Waste Act No. 59 of 2008).

In the context of the current global environmental trends, marked by extreme weather events emanating from anthropogenic waste, the conceptualization of inert CDW as posing little environmental threat requires further investigation. It is argued that the environmental performance of waste goes beyond matters of toxicity, how toxins have the propensity to disrupt bodies, and how they function. There are existing studies, albeit limited and largely ignored, which attest to this view, where inert CDW disrupted ecosystem functionality (e.g. Staunton et al., 2015; Ishigaki, 2017). The environmental performance of CDW extends to properties such as its ubiquity and high volumes. A view of CDW management studies through the lens of these properties exposes scientific studies to a rather overlooked paradigm of environmental studies that is critical for conservation and policy formulation.

It is however important to note that, regardless of the nature of existing studies on CDW across many parts of the world, there is growing consciousness of the potential environmental catastrophes that can be caused by the waste stream outside of its innate chemicals. As an example, there is a growing number of policies that encourage closed-loop systems to avoid or minimize the generation of waste. Examples can be drawn from the 'Waste Framework Directive 2008/98/EC' passed by the European Union (European Commission, 2008), and the 'EU Construction and Demolition Waste Management Protocol' which focuses on increasing confidence in recycled aggregates. The promulgation of legal instruments to effectively manage CDW is a crucial step towards achieving environmental sustainability because the waste stream constitutes 82.7% of the annual solid waste from economic activities in Europe (Eurostat, 2009) or 820 million tons per annum in the same region (Eurostat, 2017), while it constitutes 30 – 40% of global waste output from commercial activities. The effectiveness of these instruments is made knowable through the high rates of recycling in some European Union countries, topping 70% annually (Wahlström et al., 2020).

There is a stark contrast with countries of the Global South, where CDW management remains a significant urban environmental problem due to a lack of appropriate reaction or effective policies. Legislations on waste management in this region appear to be generic, and they lack the rigour required to effectively manage voluminous and often hazardous waste streams like construction waste. Emerging from this is the inability of urban authorities to cope with the high volumes of CDW generated by the expanding construction industry. To demonstrate this, in the context of Southeast Asia, some countries have attempted to recycle CDW. However, the rate of recycling is as low as 3% in some Chinese regions (Huang et al., 2018), while it is generally as low as 10% in Southeast Asia (Hoang et al., 2020; Wang et al., 2022). Similarly, only 36% of CDW generated in some West Asian countries like Kuwait is recycled, whereas the rest is either landfilled or dumped (Almusawi et al., 2022). The same applies in the context of Southern Africa, where legislation is generic and weak, thereby scoring limited success, more so because waste producers have a long history of evading compliance with the law (Godfrey & Nahman, 2010). A good example of this problem can be drawn from South Africa, where just 11% of the total CDW is recycled per annum, while the rest is either landfilled or illegally disposed of (DFFE, 2020). This nature of waste management has far-reaching ramifications, not only on municipal finances but also on environmental sustainability. Existing studies show that because of weak legislation or enforcement, countries like South Africa experience illegal dumping on a massive scale on roadsides, open spaces, isolated places, and largely in wetland ecosystems (e.g. Mangoro & Kubanza, 2023).

## 1.2. Thematic considerations

The world is currently facing massive environmental problems due to poor CDW management. Developed countries have responded to this problem through formulation of local and regional policies to encourage environmental sustainability in construction. For example, the European Union (2008) passed the 'Waste Framework Directive 2008/98/EC' and the 'EU Construction and Demolition Waste Management Protocol,' which focus on increasing confidence in recycled aggregates. This coordinated response to effectively manage CDW has led to high levels of recycling in the European Union and other developed countries (e.g. Wahlström et al., 2020). However, while developed countries actively respond to the environmental threats of CDW, developing countries in sub-Saharan Africa (SSA) such as South Africa have yet to take noticeable action on the same problem.

Waste governance in South Africa continues to be reliant on generic policies that offer very little to encourage environmental sustainability in sectors such as construction. For example, the National Environmental Management Waste Act No. 59 of 2008 is used as a guide to manage CDW. The National Environmental Management Waste Act No. 59 of 2008 classifies CDW as general waste that does not pose an immediate threat to the environment. The Act also permits landfilling of CDW and speaks very little about circularity in construction. This view of CDW presents a number of problems. Firstly, like many other countries in SSA, South Africa is currently experiencing fast urban expansion, both in terms of human population and the construction sector. Expansion of the construction sector means that new buildings are constructed, and old structures are either demolished or altered to cater to human infrastructural needs and to adapt to the current environmental trends. While the expansion of the construction sector aids economic growth, it also leads to a massive generation of CDW, which has the potential to cause environmental deterioration in the absence of strong institutions and coherent policy. Existing data suggests that the construction sector has generated approximately five to eight million tons of CDW annually since the early 2000s (Benjamin, 2004; DEA, 2018). In the absence of circularity in the construction sector, five to eight million tons of CDW means that landfill space is rapidly consumed, which raises the need to establish new spaces for disposal. Furthermore, this approximation is likely to be inaccurate, because the population of South Africa has expanded in the last two decades, which entails higher waste generation (Mangoro & Kubanza, 2023). The Department of Forestry, Fisheries and the Environment acknowledges that CDW data collection is poor and inaccurate, raising doubts on the validity of reported figures (DEA, 2018). Secondly, the directive to landfill 'general waste' such as CDW without pretreatment causes rapid consumption of landfill space, and this is a common problem in South Africa (Simelane, 2017). Additionally, due to the weaknesses of the Waste Act and poor law enforcement, massive illegal dumping of CDW has become common in the major cities of South Africa, and this manifests through volumes of waste left by roadsides and in open spaces, but mostly in wetlands located in low-income areas (e.g. Kings, 2013; Bega, 2018; IOL, 2023).

This is a major environmental problem because wetlands are crucial ecosystems that require collaborative effort for effective conservation and management. Extensive studies have been done to document the importance of wetlands. For example, several scholars argue that wetlands reduce flood risk by capturing river currents and their loads, and eventually release them back into river systems (Mitsch & Gosselink, 2000; Mandishona & Knight, 2022). Other studies suggest that wetlands offer habitat to a wide variety of aquatic organisms (Mitsch & Gosselink, 2000), while also providing freshwater and nutrient support (Rebelo et al., 2010). In addition to these important environmental functions, wetlands also play a crucial role in capturing atmospheric carbon through the process of sequestration (Kolka et al., 2022). This is a crucial ecological function, especially in the period of increased carbon dioxide emissions which contribute to climate change. For humanity, wetland ecosystems also provide several important benefits. Some studies reveal that wetlands are used for agricultural purposes (Mandishona & Knight, 2022a, b), while others argue that wetlands provide a space for cultural activities such as worship (Margaryan et al., 2018). In addition to this, studies have classified South Africa as a 'water scarce' region, which means wetlands are a crucial source for water supply throughout the year. It is obvious from the functions stated above that wetlands require care, and this stresses the importance of academic studies on sustainable use, protection, and conservation of these landforms.

On the basis of the above-stated issues, this study was based on three important issues. First, the study investigated CDW management processes in South Africa. The purpose of this was to generate an inventory of the barriers to sustainable CDW and propose ways for improvement. Additionally, the study investigated the current methodological approaches deployed in the management of CDW in South Africa to propose a suitable and sustainable methodological approach for South Africa. Lastly, this study investigated how CDW affects how wetlands function.

In view of the above-stated areas of focus, this study was guided by the study questions listed below:

1. What are the barriers affecting sustainable construction and demolition waste management in Johannesburg and Ekurhuleni, South Africa?
2. What are the effects of construction and demolition waste on wetland functionality in Johannesburg and Ekurhuleni, South Africa?
3. In what way can construction and demolition waste management be done in a sustainable way in South Africa?
4. In what ways can demolishers and constructors collaborate to sustainably manage demolition waste?

### 1.3. Studies aim and objectives

The aim of this study was to examine construction and demolition waste management processes in sub-Saharan Africa with a specific focus on South Africa. The specific objective of this study was to investigate and comprehend the barriers to sustainable construction and demolition waste management in South Africa, and the effects of the waste stream on wetland ecosystems. The study was anchored on the assumption that, despite the abundance of literature suggesting that construction and demolition is not a significant environmental threat, it depends on where it is located. Against this background, the specific objectives of this study are listed below:

I. To create an inventory of the challenges affecting the management of demolition waste and their attunement to the management of wetlands in South Africa.
II. To investigate the environmental performance of construction and demolition waste in the context of wetlands.

III. To propose a suitable methodological approach to construction and demolition waste management in sub-Saharan Africa, using South Africa as a case study.
IV. To propose ways in which relevant stakeholders can collaborate to effectively manage construction and demolition waste.

### 1.4. Theoretical considerations and literature review

Geographers, environmental scientists, and cognate field researchers have a long history of studying material culture and how material interacts with the environment. In this disciplinary tradition, 21st-century researchers from these disciplines turned their attention to CDW management issues, particularly in developing countries where most theoretical discourses emerge. The emergence of studies interest in this scholarly discourse emanated from the growing volumes of CDW and its perceived effects on the environment (Elshaboury et al., 2022). A critical synthesis of this literature revealed two major ways of doing studies in this study area. The first school of thought investigates the effects of the extraction of construction materials from the environment on different components of nature (Ampofo-Anti, 2009; Mehra et al., 2021). Among the common findings of this study is that the extraction of construction materials leads to the depletion of natural resources and an increase in carbon dioxide emissions in the affected area (Mehra et al., 2021). Depletion of natural resources is a major environmental problem because the earth's materials are finite, therefore continued extraction presents major sustainability problems. In relation to this, studies have found that continued extraction of materials from the environment destroys habitats (Bewiadzi et al., 2019). Destruction of habitat leads to loss of life or displacement of organisms, which ultimately has negative effects on environmental equilibrium (e.g. Chu & Karr, 2019). While environmental rehabilitation is encouraged in the aftermath of materials extraction, it is important to note that massive earthworks cause permanent damage.

In addition to the above, the second school of thought investigates the environmental impacts of hazardous CDW (e.g. Muigai et al, 2013; Ametepey & Ansah, 2015; Staunton et al., 2015). Examples of hazardous CDW include asbestos, oils, and plasterboard among others (Kazan-Allen, 2019; Tokpah, 2023). This category of CDW is persistent, and it lingers in the environment for extended periods, causing continuous damage until remediation is conducted. Depending on the location of disposal, toxic CDW can cause water, air, and soil pollution (Staunton et al., 2015; Wahlstrom et al., 2019; Tokpah, 2023). For example, a study found that toxic CDW can affect marine organisms through the process of bioaccumulation (e.g. Staunton et al., 2015). Bioaccumulation involves the migration of toxins or toxicants from material culture into living bodies over time (DeBlonde & Hartemann, 2013). Another study found that toxic CDW such as asbestos can permeate the soil through abrasion, and pollute underground water (Emmanuel et al, 2014; Tokpah, 2023). It is therefore not difficult to comprehend why there is recent increased attention on hazardous CDW in academia.

It is important to note that the studies traditions discussed above bears precedence in the field of chemistry or related fields (e.g. Balayannis, 2018). In such fields, the environmental performance of materials is framed through the lens of the embedded toxins and how the associated chemicals affect entities such as water, soil, various animal and plant species, humans, soil, and climate (e.g. Emmanuel et al, 2014). While this study's focus contributes to the scientific understanding of hazardous waste, it trivializes the complexity of CDW and its potential to affect the environment. Following the tradition of eco-toxicological studies, scholars typically categorize CDW into 'inert' and 'non inert' classes, where the latter category is treated with significant caution because of its associated chemicals. On the other hand, the lack of active chemicals associated with inert waste is perceived to be less of a threat to the environment, and therefore it is treated as 'general waste' that can be landfilled without pretreatment (e.g. SA National Environmental Management Waste Act No. 59 of 2008). This conceptualization of CDW has massive environmental ramifications because it informs waste policy around the world.

Although there is a general academic consensus that the bulk of CDW presents a limited environmental threat, there is growing consciousness among researchers that this view can be challenged. For example, some scholars have deviated from the conceptualization of CDW through the lens of toxicity and argue that CDW is dangerous to the environment through the rapid consumption of landfill space (Simelane, 2017; Siddiqua et al., 2022). Other studies summarize that general CDW generates visually unattractive surroundings and causes the loss of valuable land (Almorza & Brebbia, 2000). Furthermore, a coterie of scholars notes that CDW generates dust that pollutes the atmosphere and disrupts the radiative capacity of the earth, changing rainfall trends among other things (Rohracher, 2001; Darkwah et al., 2018; Kaluarachchi et al., 2021; Mehra et al., 2022). While these are interesting and useful findings, a close examination of this body of literature suggests that these environmental risks are less often the main subject of studies, but only peripherally mentioned issues (e.g., Fitchett, 2017). With this observation, it becomes clear that much research is required to fully comprehend the environmental performance of CDW, especially in developing countries like South Africa, where waste management studies are generally in the developmental stages when compared to developed countries such as the United States of America, Germany, France, and Great Britain.

Despite the emerging realization that both inert and non-inert CDW can negatively affect the environment as illustrated above, more research is required in developing countries such as those in SSA. Future studies must investigate how CDW can affect different environmental ecosystems, and this is important because different ecosystems can be affected by waste in different ways. For example, as this study will demonstrate in the following chapters, even though inert CDW does not leach toxic nutrients, it can negatively affect crucial ecosystems like wetlands through its physical characteristics such as volume and weight.

As the main subject of this study, it is imperative to note that the ability of wetlands to function normally is strongly dependent on the availability of all required conditions such as the absence of foreign solid matter. But what are wetlands? By definition, wetlands are "…areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed six meters" (Ramsar Convention Secretariat, 2016: 3). Wetlands are also defined as landforms taking up the form of swamps, bogs, fens, marshes, and wet grasslands (Staunton et al, 2014). A critical analysis of these definitions shows that the main features of wetlands include water and a drainage basin. This means that for optimum functionality, wetlands are dependent on the absence of materials that can disrupt this natural setup. In addition to this, although the above-stated definition may be slightly different in different studies, there is a consensus regarding their ecological functions and contributions.

Wetlands are linked with the function of attenuating floods, and this is achieved through wetland vegetation and peat (e.g. Gisselman, 2015). Wetlands also provide habitat for various aquatic species (Kumar & Kanaujia, 2014). Furthermore, wetland ecosystems are associated with the function of capturing carbon through the associated vegetation, and this is a significantly important function in a period of changing global climate. In addition to these critical functions, wetlands provide both humans and wildlife with water (Mandishona & Knight, 2022a, b). Furthermore, wetlands have cultural functions for humans where they can be used for agriculture or religious purposes, among others (e.g., Mandishona & Knight, 2022a, b).

Regardless of this highly studied and documented significance of wetland ecosystems, there is increased illegal dumping of CDW in these water bodies across South Africa, especially in low-income areas like informal settlements (Fitchett, 2017; Mangoro & Kubanza, 2023). What is particularly concerning, according to the literature, is that South African local government institutions lack the finances, human resources, and administrative capacity to respond to rapidly growing environmental problems (see Godfrey et al., 2013; Kubanza et al., 2021). Among the major issues with South African municipalities is alleged corruption and lack of skills to manage municipal affairs (Godfrey et al., 2013). Furthermore, due to nepotism or fraudulent recruitment processes, many officials in municipalities lack the competence required to effectively deliver their mandate (Laubscher, 2012). When viewed in the context of urban wetlands and CDW management in South Africa, it is not an exaggeration to argue that the threat of massive wetland loss will continue to grow.

### 1.5. Justification and significance of the study

Solid waste management (SWM) studies in South Africa started to gain attention immediately after the end of apartheid in 1994 when service delivery problems started to emerge. A bibliometric analysis of SWM studies in South Africa conducted by Ndou & Rampedi (2022) corroborates this view. These scholars argue that SWM studies in South Africa emerged around 1996 with only a few studies articles published per year, and this trend appears to have continued to date (see Ndou & Rampedi, 2022). Much of the studies, as Ndou & Rampedi's (2022) study revealed, focused on municipal solid waste management. An analysis of this literature showed that many of the studies is generally narrow in scope because they focus on only a few aspects of SWM. Among other major issues addressed in this study are investigations into barriers affecting SWM studies in South Africa and ways to improve the situation (e.g., Godfrey, 2013; Strydom, 2018; Nyika et al., 2019; Debrah et al., 2022). Further analysis of this body of literature suggested that much of it was motivated by ubiquitous cases of environmental crimes such as illegal dumping and poor waste collection across the major cities of South Africa.

Apart from the body of literature investigating barriers to effective SWM in South Africa, other scholars shifted their attention to issues of inclusive governance, where community participation emerged as a major theme (e.g. Boswell, 1997; Mazinyo, 2009; Kubanza, 2021; Kubanza et al., 2021). A deeper analysis of this scholarship indicates a close relationship to studies on the barriers to effective SWM in South Africa, further illustrating the lack of diversity in existing knowledge. Regardless of this situation, a coterie of scholars focused on the pressing issue of the environmental performance of municipal solid waste and proposed measures for the improvement of governance (e.g. Fitchett, 2017; Haywood et al., 2021; Mangoro & Kubanza, 2023; Ngalo & Thondhlana, 2023). Although this study was conducted by a few scholars, it revealed a crucial avenue of SWM studies in South Africa. However, together with the body of knowledge discussed so far, studies into waste in South Africa generally remains confined to the limits of common municipal solid waste generated in households. Studies attention on municipal solid waste largely produced by households leaves a significant study gap as far as other waste streams are concerned. This is major deficit in SWM studies in South Africa, especially with the rapid growth in the quantities of CDW in recent decades. This approach to waste management studies leaves significant gaps in the SWM studies discourse at large. This view is aided by the observation that many of the studies on SWM focus on terrestrial environments and peripherally refer to freshwater ecosystems such as rivers and wetlands. This study narrowed this gap by investigating the impacts of CDW on wetland ecosystems in the City of Johannesburg and the City of Ekurhuleni. It is however important to note that while studies on CDW is generally limited, attempts have been made in the recent decade. This study however is significantly limited in scope because it largely focuses on ecotoxicological analyses of construction materials and the methods deployed in managing the waste stream, while advancing generalisations that inert CDW poses a limited threat to the environment.

Among the issues most noticeable in existing CDW studies is attention to circularity in construction (e.g. Bester et al., 2017), and the methods used to quantify waste in construction (e.g. Berge & von Blottnitz, 2022). Yet, although studies by Bester et al (2017) investigated the adoption of closed loop systems in the South African construction sector to eliminate waste, as encouraged globally, the study was too narrow, and it produced negative results. In this study, Bester et al (2017) investigated the properties of concrete made using recycled aggregates and found that a considerable amount of strength was lost. While this study provided important scientific insights to players in the construction sector, it focused only on a small component of circularity and overlooked salient issues such as the need for circular methodologies that suit the needs of a developing country like South Africa. The same applies to studies by van Wyk (2014) and Sibanda (2017), where the scholars generically emphasized the need to adopt the 'waste management hierarchy' and reduce waste without providing context-specific ways of achieving this. The concept of 'waste management hierarchy' or circular economy is highly encouraged on the international stage, but it is critical to note that a one-size-fits-all approach is ineffective, particularly when technological and economic disparities between developed and developing countries are considered. Against this background, SWM in South Africa, and particularly CDW, remains largely understudied despite the environmental risks potentially caused by the waste stream.

While these studies are important, the lack of attention on the environmental performance of inert CDW can no longer be ignored. In addition to this, it is no longer a tenable approach to ignore the performance of inert CDW in aquatic environments where much of the dumping is occurring across South Africa, especially in the case study areas. In this perspective, this study investigated the environmental performance of CDW in the context of wetland ecosystems, because there is an increased onslaught of illegal dumping in these spaces (e.g. Mangoro & Kubanza, 2023). It is important to note that wetlands have risen in environmental significance in the period of anthropogenically-induced climate change and other disasters. For example, the role played by wetlands in flood attenuation, carbon sequestration, habitat supply, and water storage among others is well documented (e.g. Ehrenfeld, 2000; Mitsch & Gosselink, 2000; Lolu et al., 2018; Rangecroft et al., 2021; Mandishona & Knight, 2022). Studies that focus on the effects of CDW on how wetlands function are particularly crucial considering the above, and yet no academic study of this nature has been conducted in South Africa, and the SSA region at large.

Another avenue of studies that has been largely ignored to date is the development of sustainable CDW management methods in the context of developing countries like South Africa. Development of such methods and approaches to CDW management rises in significance when the illegal dumping onslaught on wetlands continues to rise in recent years, especially in the low-income areas of South Africa. Although sustainable CDW methods already exist on a global scale, the application of these methods in the context of developing countries requires some attunement due to technological and economic disparities between developed and developing countries. Against this background, there is a tremendous need for studies in South Africa that aims to generate financially and technologically sustainable methodological approaches to CDW management.

The findings of this study present opportunities to various stakeholders such as urban planners, local communities, and environmental NGOs to improve CDW management strategies in Johannesburg and Ekurhuleni. This is crucial because sustainable CDW management in the two cities enhances the preservation and conservation of wetlands and associated species such as the giant bullfrogs found in Diepsloot wetlands (e.g., Mangoro & Kubanza, 2023). Ultimately, the findings of this study present a model of sustainable CDW management in South Africa and other developing countries at large. This is critical especially because most developing countries around the world face similar problems with CDW management.

### 1.6. Methodological approach.

This study was co-inspired by the interpretivist studies epistemology and the 'more-than-human' philosophical approach. Interpretivism foregrounds that reality of things is a social construction and it is understood subjectively based on prior experiences (Orlikowski & Baroudi, 1991; Walsham, 2006). A view of the world through the lens of interpretivism best suited this study, because it is grounded in multiple epistemic communities comprising actors from different backgrounds, and whose conception of the reality of the 'world of waste' and its intersection with the physical environment as a human frontier differed. For the scholar, an interpretivist epistemology requires that the researcher interprets data using their own reasoning (Myers, 2008). Interpretation of data using an interpretivist approach means that the researcher makes sense of the data based on their conception of the world based on their prior experiences, and not necessarily through the view of study participants. To reduce the possibility of this, the researcher consciously remained focused on the views of the participants even when they contradicted their prior views.

Working additionally through the lens of the more-than-human philosophy, this thesis went beyond the view of humanity as the only moral actors on planet Earth (post-humanism) (e.g. Balayannis, 2018). More-than-human philosophies foreground that the world is co-inhabited by both human and non-human actors, which are all equally significant and replete with agency (de Souza, 2021). A more-than-human philosophy is grounded in an ethics of care, which posits that moral care must be extended to actors or things that are distinct from humanity (Haraway, 2003). As applied in this thesis, a more-than-human philosophy made it possible to interrogate why the CDW is illegally dumped into wetlands to provide illicit human profits through environmental crime. It is held in this study that wetland ecosystems are equally important as humanity and aquatic organisms and that through illegal dumping, wetlands have agencies that can affect humanity and fauna negatively (floods, loss of water, loss of habitat, etc.).

The study strategy deployed in this thesis was qualitative, where the perspectives of epistemic communities on CDW management processes and their effects on wetlands were investigated through questionnaires and interviews in a multi-site ethnography. An interpretivist research epistemology was best for this qualitative study, because it allowed the investigator to understand the different perspectives of experts based on their various professional or institutional backgrounds. In interpretivism, study participants draw on their background or prior experiences to understand the world (Walsham, 2006). This was considered crucial for this study because different notions of CDW management in South Africa and how wetlands are affected by waste is crucial for the formulation of new ways to achieve environmental sustainability. Crucially, a qualitative design works well in an interpretivist research epistemology where non-numerical data like participant feelings and judgements of a given phenomenon can be gathered and analysed (see Walliman, 2011). The adoption of an interpretivist research epistemology was further encouraged by the investigator's prior knowledge of the study area through the work on solid waste management (e.g. Mangoro & Kubanza, 2023). In addition, several relationships with officials from different environmental organizations and activists in the area had been developed over a few years. Therefore, perspectives gathered during this period were crucial in the investigator's conception of the study area and the study problem.

In any qualitative study, it is crucial to recruit the maximum number of respondents from a given area e.g. the whole of South Africa. A study of such a scope provides data or perspectives that are highly representative of the given population. However, due to problems with limited time and finances, this was impossible to carry out. For this reason, the study sites were limited to low-income areas of Diepsloot and Tembisa located in the City of Johannesburg and the City of Ekurhuleni Municipalities in the Gauteng Province. Some wetlands in these locations are highly targeted for illegal dumping of CDW, making it a suitable study site. Furthermore, the area is characterized by a multiplicity of epistemic communities suitable for this study (Figure 1.1). The study was based on the perspectives of 45 experts recruited from various epistemic communities in the City of Johannesburg and City of Ekurhuleni. Although the study would have benefitted from more participants, 45 experts were considered sufficient because the research is based upon a hybrid methodology comprising expert interviews and GIS/Remote Sensing techniques.

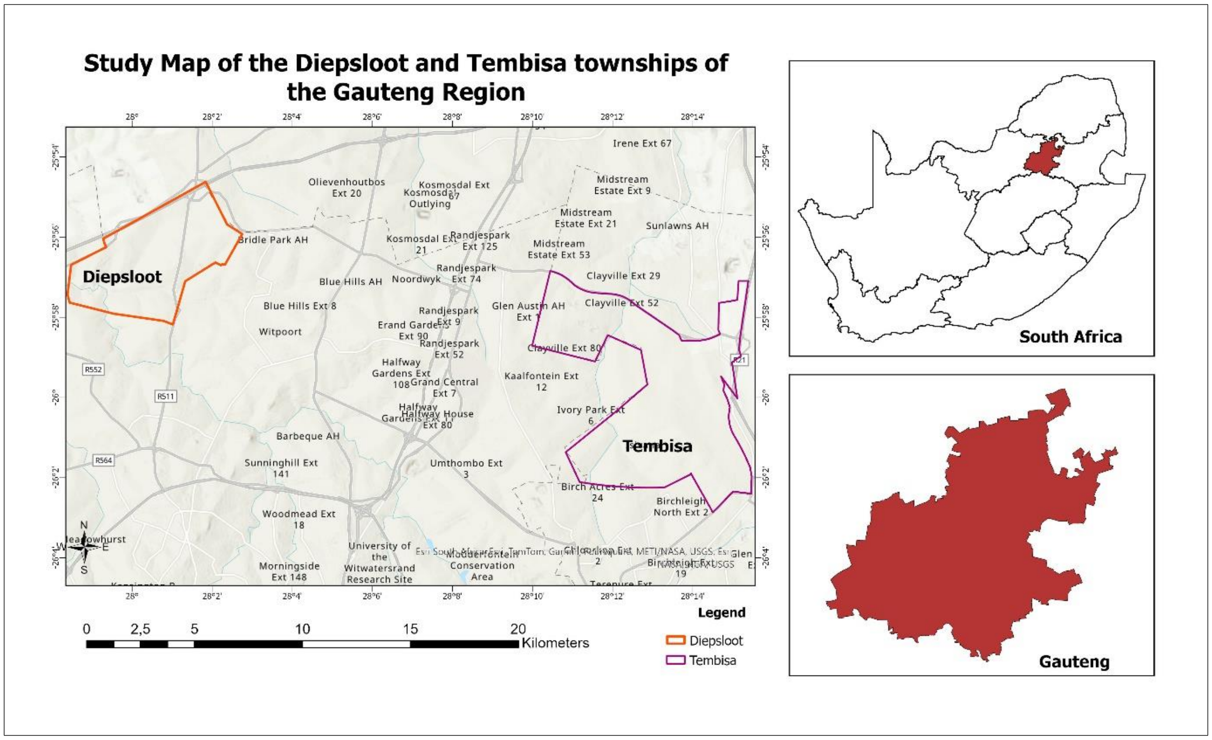


**Figure 1.1 Map showing the general study area**

*Source of Map: Researcher, 2023.*

## 1.7. Studies design

*a. Description of the study areas*

This study was based on a multi-sited ethnography involving two low-income areas of Diepsloot (25.9396°S, 28.0128°E) and Tembisa (26.0093°S, 28.2181°E) in the Gauteng Province of South Africa. The two settlements are geographically located in the Johannesburg Metropolitan Municipality and the Ekurhuleni Metropolitan Municipality respectively (Figure 1.1). The two study areas were built according to the apartheid urban settlement planning style, which sought to segregate Black African communities from White settlers during the colonial period (Benit-Gbaffou, 2002; Benit-Gbaffou et al., 2013). Both the study sites are characterized by formal and informal housing units that are densely clustered.

However, it is important to note that the informal settlements developed largely in the last twenty years due to population growth and shortage of housing in democratic South Africa (e.g., Mangoro & Kubanza, 2023).

As illustrated in Figure 1.1, both study sites are in a landscape that is replete with streams adjoining the Jukskei and Kaalspruit Rivers catchment system. Recent water quality studies on the two permanent rivers reveal massive contamination emerging from agricultural and mining effluent (e.g. Hoorzook et al., 2021; Morole et al., 2022). Although these studies provide critical information on pollution and water quality associated with the two rivers in recent years, there is general silence on the quality of wetlands associated with these river systems.

Therefore, the choice to study wetlands associated with the Jukskei and Kaalspruit Rivers in Diepsloot and Tembisa was influenced by the general lack of academic interest in these throttled ecosystems despite their critical role of filtering the heavily polluted currents due to incessant deposits from mining, agricultural activities and sewage spillage. Furthermore, the decision to investigate the functionality of wetlands connected to the Jukskei and Kaalspruit River system was informed by the abundance of solid waste (CDW), rather than effluent which captured the attention of eco-toxicological studies in the area (Hoorzook et al., 2021; Morole et al., 2022). Furthermore, the wetlands investigated in this study are some of the largest and most ecologically important in the northern areas of metropolitan Johannesburg and Ekurhuleni. For example, some studies reveal that the wetlands along the Jukskei and Kaalspruit rivers form a habitat for the near-endangered giant bullfrog species or *Pyxcephalus adspersus* (e.g. Yetman & Ferguson, 2011; Mangoro & Kubanza, 2023), whereas their riparian zones are associated with the Grass owl or *Tyto capensis* (Envirolution Consulting, 2018). These factors made the study area and sites crucial for this multi-site ethnography.

*b. Study population and sampling procedure*

For this qualitative study to be conducted, several study participants were required for data collection. To recruit the participants, a sampling criterion was required to determine the best-suited organizations or individuals to participate in the study. Sampling is a crucial recruitment criterion in a study because it eliminates the need to recruit all possible participants to get the best-informed datasets (e.g. Omrod, 2005). Thus, sampling saves time and resources while achieving effective study outcomes. However, it is important to note that there are several types of sampling, and that each sampling method is fit for a particular studies question (Dawson, 2013). It is on this basis that judgement or purposive sampling (non-probabilistic) was deployed. Purposive sampling is defined as deliberate selection of studies participants based on their qualities and how they can best suit a given study (e.g. Etikan et al., 2016). The purposive sampling strategy was best for this study because it allowed the researcher to first investigate the mandate or scope of epistemic communities, and recruit participants based on their institutional roles and how these roles had a bearing on the current studies (see Etikan et al, 2016).

To acquire data for this study, participants were recruited only from epistemic communities or expert organizations, and not local communities. This choice was informed by the fact that the study required expert opinions on how wetlands function, and what the effect of CDW was on the way wetland ecosystems function. Although local communities might have had general knowledge about wetlands, this study was more interested in expert opinions and not general community perceptions. Based on this, participants were recruited from several epistemic communities including construction companies, environmental non-governmental organisations, the City of Johannesburg Municipality, the Department of Forestry, Fisheries and the Environment (DFFE), and the Gauteng Department of Agriculture, Rural Development and Environment (GDARD). Participants from these organizations were deemed to have sufficient knowledge on the issues under investigation and were selected based on purposive sampling, as stated above.

First, one or two participants were purposively recruited from each organization to establish a starting point for the selection process. Once this was completed, the snowball sampling strategy was introduced to recruit other suitable experts in line with the goals of the study as outlined in the earlier sections of this chapter. Snowball sampling is a method used to recruit participants who are not easily accessible to the investigator for different reasons (Naderifar et al., 2017). For this study, some participants were not easily accessible because they were not listed on company websites, and only officials from the selected epistemic organizations could have assisted in identifying them. Once the snowball sampling strategy was deployed, a total of 45 experts were recruited for this study from the organizations listed above.

Data collection from the selected participants was achieved using telephonic semi-structured interviews and face-to-face interviews. These data collection strategies were informed by several reasons. First, some participants were not in South Africa at the time of data collection and could therefore only be interviewed virtually. Second, due to the COVID-19 pandemic and the national lockdown rules at particular times, other participants were also interviewed through virtual means. Third, some participants preferred questionnaires rather than interviews or face-to-face conversations because they did not have much time during business hours. Due to varying times of availability, the data collection period lasted from March 2022 to June 2023. All the study participants worked for organizations in Gauteng.

## 1.8. Ethical Considerations

Every study carried out must produce valid and reliable data following academic or professional best practices (Clough & Nutbrown, 2002; Merriam & Tisdell, 2016). It is argued that for studies to contribute to the development of a field, they must be done in a rigorous manner, must present data that suggest truth, and protect studies participants (Merriam & Tisdell, 2016). Therefore, ethical practice was a matter of professional responsibility for the researcher. To achieve ethical competence, the researcher attended an ethics studies workshop organized by the University of the Witwatersrand Non-Medical Ethics Committee. In this workshop, attendees were educated on how to conduct ethical studies, and their competence was tested through several assignment questions. The researcher was able to adequately respond to the assignment questions, and a certificate was issued as a declaration of competence (ethics clearance or protocol number - H22/07/19).

Once the ethics training process was completed and the competence certificate was issued, the data collection process commenced. This process began with sending out invitations, participant information sheets, and consent forms in order to adhere to ethical practices associated with participatory studies. Participant information sheets described the purpose of this study while consent forms sought permission on how to use the collected data. Both documents required signatures as a proof that all participants were willing to be involved in the study (see Robson, 1993; Clough & Nutbrown, 2002). In addition to this, aspects of anonymity and confidentiality were also explained to the participants thoroughly in order to impart a sense of security in them.

Several other ethical issues such as anonymity and confidentiality are of ethical significance (Merriam & Tisdell, 2016). With regards to anonymity and confidentiality, data collected from participants will be stored in a password-secured internet cloud. In addition, hardcopy transcripts will be stored in a lockable cabinet in the Wits University PhD Geography laboratory for a period of two years.

### 1.9. Structure of the thesis

This thesis was compiled by way of publication. It consists of three journal articles, each representing the chapters of a traditional thesis by monograph. **Chapter 1** presents the study's conceptualization where the study focus was conceived. It comprises the background to the study, research questions, aims, and objectives of the thesis. Additionally, Chapter one also presents the research methodology and structure of the study. This is followed by **Chapter 2**. This is based on a published journal article which investigated the barriers to sustainable construction and demolition (CDW) management in sub-Saharan Africa, with a special focus on South Africa. **Chapter 3** follows the above, and it was also based on a published journal article that focused on the environmental impacts of CDW on wetlands using Diepsloot and Tembisa low-income suburbs in Johannesburg and Ekurhuleni. This was subsequently succeeded by **Chapter 4,** which was also based on a journal article. This article focused on the current methodological approaches to CDW management across the world with a focus on South Africa. The article proposes an appropriate method for sustainable CDW management in the context of South Africa. **Chapter 5** presents a general discussion of the findings of the entire study. Finally, **Chapter 6** provides a summary and conclusion to the study. It provides an overview of the study and recommendations for future studies in CDW management in the context of South Africa and other developing countries in SSA.

# CHAPTER TWO

# THEORETICAL CONSIDERATIONS AND LITERATURE REVIEW

**Overview of the chapter**

This chapter is composed of a peer-reviewed publication that focuses on theoretical considerations and a literature review on construction and demolition waste (CDW) management. The spatial focus of this chapter is the entire world, to provide a comprehensive understanding of CDW processes and challenges. The significance of this chapter is to provide an overview of the theoretical debates on CDW management and understand the associated viability concerns.

This chapter notes the increased studies attention on CDW management processes in the recent decade, where the theme of urban environmental sustainability appears to be central. Among the major arguments emerging from this literature is that CDW has become a major urban environmental problem which is motivated by several causes, especially in the context of developing countries. It is argued that CDW comes in packages and volumes that require massive financial investment for effective and sustainable management (e.g. Napier, 2016; Illankoon & Lu, 2019; Fitchett & Rambuwani, 2022). In this study, it is argued that CDW management will continue to be major urban environmental problem for city managers, particularly in developing countries such as in sub-Saharan Africa (SSA) where the human population is predicted to rapidly increase in the next few decades.

The published journal article in this chapter comprehensively discusses the barriers to effective and sustainable CDW management across the world. In the first section of the literature review, the article engages with scholarly debates on the barriers to CDW management from developed and developing countries outside of SSA such as in Europe, America, and Asia, among other continents. In this section, it is found that the barriers to CDW are largely similar, although developed countries appear to have the capital and technologies required to reduce the environmental burden associated with waste. This contrasts with developing countries, where living standards are significantly lower. This draws attention to issues of human subsistence rather than environmental affairs such as CDW management.

This section is followed by a synthesis of the literature on CDW management barriers in SSA countries. In this context, it is found that countries in SSA also face homogenous CDW management challenges such as institutional, technological, and legal problems. However, barriers to CDW management in SSA appear to be more accentuated in South Africa where there is rapid expansion of the construction sector and massive production of waste.

To address these problems, this chapter suggests several solutions, including the adoption of deconstruction where demolition is done systematically. This approach to demolition makes it possible to salvage reusable material and minimize the production of waste. It is also argued that universities can be incorporated into CDW through introduction of courses in sustainable waste management strategies in construction. This is an important recommendation because there is a scarcity of knowledge on sustainable CDW management in South Africa and the rest of the region. Finally, this chapter also recommends the establishment of an online-based CDW management platform where information exchange is central. The formation of this platform is crucial in the exchange of waste materials that can be used in other construction projects and to minimize the environmental impacts of CDW.

**Paper No. 1**

# An Assessment of Literature on Construction and Demolition Waste Management Barriers in Sub-Saharan Africa: Lessons and Implications for Sustainability in South Africa[1].


## ABSTRACT

This paper discusses the challenges associated with the management of construction and demolition waste and its implications on environmental wellbeing and sustainability. Using existing and anecdotal literature, evidence suggests an increase in the demand for infrastructure for domestic and commercial purposes, and this in turn is exerting massive pressure on the construction industry to absorb and meet increased levels of demand. This development has however, been accompanied by the generation of excessive quantities of waste, making it extremely difficult for urban managers in Sub-Saharan African cities to manage construction and demolition waste effectively and comprehensively, a major challenge being that this type of waste exists in forms that require extensive injection of resources for systematic separation far beyond the budgetary positions of many of these cities. In view of this, this paper is an attempt to systematically review and synthesize existing knowledge with a view of creating an inventory of the challenges associated to construction and demolition waste management and suggest possible solutions and approaches for transforming this waste into a resource.



**Keywords:** construction and demolition waste, urban managers, sustainability, barriers, environment, circularity, challenges.


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[1] This chapter has been published in its current form: Mangoro, N., Kubanza, N.S. & Simatele, M.D. (2023). An Assessment of Literature on Construction and Demolition Waste Management Barriers in Sub-Saharan Africa: Lessons and Implications for Sustainability in South Africa. International Journal of Environment and Waste Management, http://dx.doi.org/10.1504/IJEWM.2023.10060718

## 2.1. Introduction

Construction and demolition waste (CDW) has increasingly become a massive challenge for urban managers across the world. Global population growth and increased industrial production in recent decades have ushered the world into a new age where the significance of the built environment has increased, causing a rapid rise in the generation of CDW (Mahayuddin et al., 2008; Dangi et al., 2017; Al-Otaibi et al., 2022; Debrah et al., 2022). Over the last decade, several scholars reached a consensus that CDW makes up 30–40% of the global waste output annually, putting construction among the highest waste-producing industrial sectors in the world (Zhao et al., 2010; Akhtar & Sarmah, 2018). Even though the growth of the construction sector can be a sign of prosperity, increased CDW production has become a significant urban environmental burden in both developed and developing countries (Ali et al., 2019; Al-Otaibi et al., 2022). To illustrate this, scholars argue that CDW can pollute riverine ecosystems such as wetlands or disrupt bodies of riverine species through its embedded chemical constituencies by gradual bioaccumulation (Staunton et al., 2014). Other investigators argue that CDW can generally pollute the atmosphere through fugitive dust from construction or demolition sites, or cause massive soil pollution (Mehra et al., 2022; Kaluarachchi et al., 2021). In response to the growing urban environmental challenges from CDW, developed countries have made tremendous strides to transform waste management laws, and to advance associated technologies (e.g. Gohlke & Martin, 2007; European Commission, 2008). Yet, despite these improvements, developed countries continue to face urban environmental challenges, and some investigators have attributed this to the model of governance associated with some economically successful countries. It is common among developed countries to follow a federal system of governance where individual states or provinces have significant legislative power and overall authority in these jurisdictions (Hyder Consulting, 2011; Gamper, 2019). A federal system of government translates to multiple pieces of legislation or regulations that affect CDW management in each country. The major issue with this situation is that it makes it very challenging to effect national or international waste management or environmental commitments (Hyder Consulting, 2011; Gamper, 2019). In addition to this, the construction sector in developed countries is faced with an endemic culture of resistance to cutting-edge waste management models such as the circular economy (CE), which advances the concepts of reduction, recycling, or reuse of waste materials (Kirchherr et al., 2017; Mawed et al., 2020). For example, in the United Arab Emirates (UAE), Italy, and Australia, construction companies remain doubtful of the quality of recycled aggregates and therefore prefer virgin materials (Park & Tucker, 2016; Mawed et al., 2020; Cárcel-Carrasco et al., 2021). Further to the above, construction personnel in developed countries have limited knowledge of the significance of sustainable CDW management because the workers lack basic training in this regard, causing significant waste production at construction or demolition sites (Yuan & Shen, 2011). Scholarly studies have established that a lack of training in waste management leads to the generation of at least a third of CDW produced in developed countries such as New Zealand, China, and the UK (Low et al., 2020). Other scholars argue that the lack of training in waste management in the construction sector results in poor architectural designs where personnel is bounded by saving time rather than preserving the environment (see Dainty & Brooke, 2004; Yuan & Shen, 2011; Low et al., 2020).

The environment, urban managers, and societies in developing countries outside of sub-Saharan Africa (SSA) have also long been affected by the rising quantities of CDW. The problems affecting CDW management in developing countries include poor record keeping of the quantities of waste generated or disposed of in landfills or other locations (Mahayuddin et al., 2008). This problem arises from the lack of organization and commitment to environmental issues, because companies are mostly concerned with profits and saving time during the construction process (Mahayuddin et al., 2008). Additionally, some investigators argue that developing countries also face the problem of weak legislation governing the handling of CDW (Mahayuddin et al., 2008). These investigators argue that CDW is regarded as general waste that poses little threat to the environment, in contrast to municipal waste which is governed by stronger and stricter legislation (Mahayuddin et al., 2008). Other studies argue that CDW management is characterized by poor law enforcement (Lu & Tam, 2013). These scholars are of the view that weak law enforcement arises from a lack of manpower and trained law enforcement officials (Lu & Tam, 2013). A lack of investment in manpower means that only a small number of personnel is responsible for law enforcement over vast expanses of territory, causing a lack of efficiency which ultimately promotes illegal CDW handling activities such as dumping. Poor law enforcement encourages illegal dumping especially because developing countries have a chronic problem of landfill space shortage.

It is important to note that CDW management barriers are also common in SSA. Yet, while some barriers appear to be like those in developed and developing countries, it is important to note that in the SSA perspective, some small yet important disparities make the problems much worse in the region. To illustrate this, just like in many countries outside of the region, SSA is plagued by weak waste laws that make it problematic to achieve sustainability in CDW management (Agamuthu, 2008). However, while many countries outside of the region such as Algeria (North Africa) and countries in Europe and Asia (e.g. Germany and Japan, respectively), have responded through the promulgation of legislation specific to CDW, SSA continues to adopt generic waste laws that classify the waste stream as general waste e.g. the South African Waste Act of 2008. This is a significant barrier to sustainable CDW management because construction firms have very little environmental obligation, such as adherence to the demands of the circular economy (Agamuthu, 2008).

The significance of tailor-made laws or regulations for CDW is demonstrated by the stance taken by countries in the European Union. Here, such laws have helped to encourage adoption of the circular economy, and in general, mandatory environmentally friendly behaviour from construction firms (Agamuthu, 2008; European Commission, 2008; Nelles et al., 2016). The challenge of weak laws is accompanied by a lack of capacity to effectively manage waste by both construction firms and local governments. Municipalities in SSA suffer from chronic underfunding (Kubanza & Simatele, 2015) whereas construction firms claim to have limited funds for activities outside of construction (e.g. Koma, 2010; Oyenuga & Bhamidiarri, 2015).

This appears to be a legitimate reason because CDW requires costly machinery for recycling, which deters willing participants from adopting circular economy principles (Oyenuga & Bhamidiarri, 2015). However, financial problems facing municipalities in SSA arise from bureaucratic challenges such as disbursement delays from the national governments rather than lack of funds (Worrall et al., 2017). In view of the problems briefly mentioned in this section, this paper focuses on a critical review of existing literature on barriers affecting CDW in the context of developed countries, developing countries, and in SSA to propose solutions in a much-localized context of South Africa.

### 2.2. Methodological considerations

The information which constitutes this article was collected through a desktop study which was conducted between March and July 2022. It involved an extensive review of existing literature focusing on the challenges affecting CDW management on a global scale, with a special focus on South Africa. During this period, data collection was conducted through a rapid evaluation and appraisal of various pieces of peer-reviewed academic literature and survey reports at global, regional, and national levels. An extensive review of archival records and peer reviewed journals on CDW in global, developed countries, and SSA context was conducted. Additionally, literature was also collected from various university libraries in the form of books (e.g. universities of Pretoria, Witwatersrand, Johannesburg, and KwaZulu-Natal). Furthermore, peer reviewed papers were accessed through online public access catalogues such as Science Direct, Scopus, and Web of Science, where complete articles or links to articles were derived. Finally, peer reviewed articles were also collected through different web-based search engines such as Google, Studies Gate, Google Scholar, and Yahoo in search of extant and recent papers on the topic under study.

Keywords or phrases used in the search for literature including 'construction and demolition waste management challenges' and 'construction waste management barriers' were entered into all the literature search platforms. Ultimately, the search for literature on all platforms produced 82 articles primarily concerned with CDW management challenges in all the geographical contexts under study, with most of them published in the last ten years. Of the 82 articles produced from the literature search, 56 were relevant to the current study. Of the 56 articles, 25 were concerned with developed countries, while 19 focused on developing countries in continents such as Asia, America, and Europe, while the remainder was focused on SSA. These articles were critically analysed and discussed in the following section.

### 2.3. Construction and demolition waste management barriers in the context of developed countries and developing countries.

A considerable body of literature reveals that CDW presents a massive burden to the environment and to urban managers in developed countries (e.g. European Commission, 2008; Staunton et al., 2014; Mawed et al., 2020). Some of the challenges faced by urban managers in developed countries in CDW management emerge from governance systems where decentralised legal systems are in place (Park and Tucker, 2016; Mawed et al., 2020). Many developed countries follow the federal system of governance, which is a formalised distribution of power between 'sovereign states' and the national or central government (Hamilton et al., 2009; Gamper, 2019; Huberfeld et al., 2020). On the political front, a federal system of governance is progressive in terms of separation of powers, because states or provinces reserve the right to enact laws or regulations governing their affairs (Hamilton et al., 2009; Huberfeld et al., 2020). This approach to governance diminishes the power of the national government in each country and foils the ability of leaders to make arbitrary or forceful decisions. In the context of environmental affairs such as CDW management however, this system of government present significant barriers to the achievement of holistic national, regional, or global milestones (e.g. Hyder Consulting, 2011; Park & Tucker, 2016; Mawed et al., 2020). In other words, a federal system of government results in the promulgation of different laws or regulations for environmental affairs setting up disparities at the local state, national, and global levels in terms of management planning (e.g. Hyder Consulting, 2011).

Federal states facing such challenges include Australia, the UAE, and the USA. National governments in these countries lack the authority to legislate CDW processes because the powers required to regulate waste management affairs rest with local state/provincial governments which are sovereign by nature (Hyder Consulting, 2011; Park & Tucker, 2016; Mawed et al., 2020). Ultimately, every state has unique local waste laws, making it difficult to work in concordance with the national governments, thus presenting a significant challenge to sustainable CDW management.

The other barrier to sustainable CDW management is the endemic lack of communication among interested parties in construction across developed countries (Gamil & Rahman, 2017). Lack of communication in each system entails disjointed processes, and ultimately, this is accompanied with catastrophic failure. In their 2017 study, Gamil and Rahman argue that the lack of effective communication systems in the construction business means that global calls to sustainability (e.g. circularity) remain largely ineffective. A useful example can be drawn from a study in the UAE, where poor communication in construction is typically associated with frequent changes in building design during building projects, resulting in a surge in the quantities of CDW produced (Yuan & Shen, 2011). To elucidate, some studies have found out that design changes during the construction phase means that more resources will be allocated to the project, eventually resulting in increased waste being generated (Yuan & Shen, 2011; Mawed et al., 2020). Thus, it can be argued that systematic and timely cohesion between stakeholders in construction before the construction phase creates opportunities for sustainable CDW management practices.

While the above argument presents opportunities for sustainable CDW management such as waste minimization, as required in the era of climate change, it must be noted that the construction sector in some developed countries holds scepticism over calls to transition to sustainable initiatives associated with the circular economy (reduce, recycle or reuse, or waste). This scepticism is largely motivated by distrust of the quality of recycled aggregates (see Mawed et al., 2020; Cárcel-Carrasco et al., 2021). Following this position, the constructor sector in some developed countries like Australia, Italy, the UAE, and Portugal continue to champion environmentally unfriendly approaches to CDW which are linked to the linear economy (take, make, dispose) (Couto & Couto, 2010; Cárcel-Carrasco et al., 2021). In these countries, it is generally believed that the circular economy in construction requires further investigation to assess its benefits despite multiple cases of scholarly advocacy for the concept (Couto & Couto, 2010; Mawed et al., 2020; Cárcel-Carrasco et al., 2021). To illustrate this, Park, & Tucker (2016), supported by Cárcel-Carrasco et al. (2021), argue that construction personnel in Australia and Italy effectively protest the much-advocated onsite waste management directive by environmentalists, which means that the separation of waste for circularity purposes is impossible.

In other contexts, resistance to the concept of circularity in countries such as New Zealand, the UK, and the UAE appears to emerge from a lack of education and training (Mawed et al., 2020). Lack of education and training on the concept of circular economy has significant impacts on the levels of waste production. In support of this position, several scholars argue that lack of education and training on the significance of circularity accounts for a third of all the CDW produced in developed countries (Dainty & Brooke, 2004; Yuan and Shen, 2011; Low et al., 2020). This is a major problem which is worsened by the fact that most construction projects in developed countries are poorly funded, which makes it difficult for construction managers to effect sustainable CDW management plans (Yuan & Shen, 2011; Mawed et al., 2020). The consequences of this are apparent in countries like Australia and China, where the effects of poor funding emerge in the form of poor CDW handling such as random mixtures of different types of CDW (Yuan & Shen, 2011; Hyder Consulting, 2011). It is noteworthy to mention that separation of waste onsite is relatively cheaper and less time consuming than practising it offsite. To illustrate this, Hyder Consulting (2011) noted that it costs about 150,000 Australian dollars to separate 600 tonnes of heterogeneous CDW waste. In view of this, it is quite difficult for construction companies to commit to waste separation and recycling (offsite), given that the initiative is undermined and poorly funded (Yuan & Shen, 2011), and the entire process increases costs to the company (Tischer et al., 2013). Therefore, it can be observed that lack of education and training on waste, and poor funding of construction projects present significant barriers to sustainable CDW management.

In addition to the challenges discussed above, it has been argued that successful CDW management strongly depends on the availability of high-quality data at the administrative level (Hyder Consulting, 2011). Yet, despite the significant improvements in CDW management in developed countries, data collection remains a lingering problem that emanates from disorganisation of the waste governance system (Hyder Consulting, 2011). This is a significant problem because policy formulation on CDW is strongly reliant on reported data. It can be argued that poor data collection or reporting misguides policy direction and approach. This problem is prevalent in some developed countries such as Australia, where wrong estimations are made because of poor weighing at weighbridges in Sydney (Hyder Consulting, 2011). This is worsened by the fact that in states such as New

South Wales, a lack of education and training on waste handling results in poor classification of heterogeneous waste, which in turn negatively affects the quantification of waste categories (Hyder Consulting, 2011). This challenge is magnified by logistical problems such as space at construction sites in developed countries (Low et al., 2020). It is a fact that CDW is one of the most voluminous waste streams across the industrial divide. This is at odds with the fact that construction sites are typically small and confined to a specific location. Construction sites in a central business district can be used as a practical example, because they are organically flanked by other buildings, narrowing space even further (Tischer et al., 2013). Such problems motivate landfilling, dumping, or other unsustainable waste handling practices in the construction sector because circularity measures such as onsite separation require large spaces.

However, CDW management barriers are worse off in developing countries such as in Asia, South America, and some parts of Europe, despite similarities in some cases. For example, developing countries also face the challenge of weak waste management laws and poor enforcement (Alotaibi et al., 2019). The weakness of these laws is made apparent by the fact that municipal waste laws are more rigorous compared to those governing CDW (Mahayuddin et al., 2008). This problem emanates from the fact that CDW is not regarded as an immediate threat to human health and the environment. The weakness of waste laws also manifests through the lack of punitive or restrictive measures such as taxation to curb the overproduction of waste or environmental crimes (Mahayuddin et al., 2008). Additionally, poor environmental law enforcement replete across developing countries is reported to be a major motivation for illegal dumping. In addition to this, there is a sense of ambiguity in environmental law regimes regarding the responsibilities of contractors in construction and governing institutions in countries such as Lebanon (Saad et al., 2022). Such a situation provides ample opportunity for poor CDW handling.

In other developing states, one of the major challenges in CDW governance is that waste management is typically under the purview of several public and private institutions or entities (Al-Otaibi et al., 2022). Some of the commonly involved entities include municipalities, private waste collectors, multiple government departments, and non-governmental organisations. Like federal law systems in some developed countries, it offers a sense of decentralisation and efficiency. However, there is no clear delineation of responsibilities for each player (Al-Otaibi et al., 2022). As a result, institutions often lack commitment to waste management issues, hoping that cognate institutions will tackle any issues that may arise (Al-Otaibi et al., 2022). Several scholars have argued that this situation arises as result of excessive bureaucracy across local and national governments in developing countries, so the duties of each institution often end up unclear and confusing (Kabirifar et al., 2021). Although this is detrimental to sustainable CDW management, some scholars embrace this position and argue that institutional fragmentation requires institutional coordination and clear delineation of responsibilities for effective service delivery (Alotaibi et al., 2019).

Construction firms in developing countries often lack awareness of social responsibility (SR), a key sign of commitment to environmental sustainability in the modern age (Alotaibi et al., 2019). However, what is social responsibility? It is a process that focuses on responsibly treating stakeholders of an entity according to international standards (Hopkins, 2003). An investigator argues that SR is committed to things such as economic, financial, and environmental responsibilities, and recognition of interested parties outside of the corporate world (Hopkins, 2003). Given this scenario, it is apparent that SR can have significant bearing on the way CDW is managed by construction companies in developing countries. In developed countries, construction firms take SR as an integral part of their business operations because it enhances their reputation by showing their commitment to people and the environment outside of their pursuit for profit. Given the significance of SR to environmental conservation, the corporate lack of awareness of the concept presents major barriers to CDW management, yet the construction industry is the largest producer of waste in the world economy (e.g. Upstill-Goddard et al., 2012).

The Kingdom of Saudi Arabia (KSA) provides a perfect illustration of corporate disregard of SR and the immediate outcomes in developing countries. CDW waste management in the KSA is characterised by landfilling or dumping on the outskirts of major cities, contributing to environmental degradation (Ouda et al., 2018). Similarly, construction firms in Peru do not place priority on environmental management instruments (EMI) (Rondinel-Oviedo, 2021). Such instruments are concerned with tools put in place before construction to manage waste outputs, and in Peru, there is an obligation that construction sites without EMI in place are exempted from adopting CDW management plans (Rondinel-Oviedo, 2021). On close inspection, it can be observed that construction firms are not legally obliged to perform with a sense of corporate environmental responsibility because it is not mandatory in this context.

Just like in developed countries, sustainable CDW management is impeded by a lack of commitment to the circular economy through the principles of the 3Rs (Reduce, recycle, reuse) to manage CDW (Bagdi et al., 2013; Saad et al., 2022). This challenge emerges from multiple angles in developing countries. Firstly, the problem is related to a lack of SR or EMIs discussed earlier in the article. Construction firms with such instruments in place would be committed to the 3Rs in waste management. Secondly, CDW comes in packages and quantities that are highly heterogeneous and therefore costly and labour intensive to prepare for the 3Rs (Ametepey et al., 2015). Therefore, since processing CDW for the 3Rs is costly, most construction firms prefer to ignore the concept of circularity (Saad et al., 2022). For example, Bagdi et al. (2013) argues that although construction firms in India are beginning to be aware of the 3Rs though the increasing visibility of on-site waste compactors, separation, and auditing, the full adoption of the circular economy remains a distant future because of the high expenses related to this. In countries such as Lebanon, this is exacerbated by the fact that construction organisations have no coordination with governing institutions regarding CDW management issues. As a result, scholars observe that there is no environmental education on construction sites before the commencement of projects, as should be the case to achieve sustainability in construction (Saad et al., 2022).

### 2.4. Construction and demolition waste management barriers in the context of SSA

To effectively manage CDW, many developed and developing countries outside of the SSA region have adopted principles of the circular economy and have taken measures to achieve its success (Agamuthu, 2008; European Commission, 2008). In SSA however, existing literature suggests that while the concept of circularity is now known, its application remains problematic just like in many parts of the world for different reasons. What is largely unique to SSA is the shortage of personnel trained in the use of CE methods in the public sector, yet abundant in the private sector, as reported in countries such as Liberia, Angola, Burundi, and the Central Africa Republic, among others (Ferronato and Torretta, 2019). A growing number of scholars argue that experts in CE methods of waste management in SSA prefer working in banking, environmental protection, insurance, and non-governmental organizations in search of more competitive remuneration (Ferronato and Torretta, 2019; EPA, 2022). This situation means that the waste management sector in SSA is largely dysfunctional because local and national governments have the constitutional obligation to ensure effective environmental management and protection (e.g. South African Constitution of 1996). This situation presents a significant barrier to CDW management because national and local governments are responsible for managing the bulk waste in SSA.

Further examination of existing literature suggests that the above barrier to sustainable CDW in SSA is likely to persist because of poor recruitment practices by local and national governments (Godfrey & Nahman, 2007; Laubscher, 2012). It is commonplace in SSA for local governments to corruptly hire unqualified and incompetent personnel in all departments, particularly in finance (Atkinson, 2003; Godfrey & Nahman, 2007; Laubscher, 2012). The effects of these flawed recruitment processes on service delivery are well documented. For example, financial management in South African and Zimbabwean municipalities is characterized by cases of chronic inability to account for expenditure, and poor service delivery (Laubscher, 2012; Marumahoko, 2020). Based on these arguments, it is not an exaggeration to argue that such issues have a direct bearing on the capacity of local governments to effectively manage CDW, which needs large sums of capital to process, and cutting-edge machinery.

The lack of personnel trained in CE methods of waste management discussed above rises in significance considering the centralization of power in SSA. Studies conducted by Erk (2014) on governance affairs in SSA suggest that decentralization only exists in theory in SSA. It is commonplace that most countries in SSA follow much more centralised forms of governance, where major decisions are passed from the upper echelons of power (Erk, 2014). Furthermore, unlike in many developed countries as discussed in the above sections, SSA countries generally do not follow the federal system of governance where individual states or provinces can pass legislation. Legislations on waste or other affairs affecting the SSA society are generally passed in the House of Assembly and enforced by national law enforcement agencies. In comparison to federal countries, this implies that countries in SSA find it relatively easy to meet global waste management goals because there are uniform laws governing the states. However, this situation brings upon CDW management challenges that are unique to SSA, because much of the municipal funding in the region is supplied by central governments (Worrall et al., 2017; COSATU, 2023). The major issue that renders this problem unique to SSA is that the funds are largely supplied very late, causing disruption of municipal operations such as waste management (Laubscher, 2012; Worrall et al., 2017; COSATU, 2023). It is important to note that the delay in the supply of funds is due to excessive bureaucracy, and this causes the funds to reach municipalities towards the end of fiscal years, causing massive disruption of service delivery (Worrall et al., 2017).

The management of CDW in SSA is further restrained by a lack of policy that is tailor-made for this waste stream (Agamuthu, 2008). This is in sharp contrast with many countries outside of SSA, such as those in Europe (e.g. Agamuthu, 2008; European Commission, 2008; Nelles et al., 2016). Even some countries in Africa (outside of SSA) such as Algeria have recognised the environmental threats of construction and passed a law to specifically manage the waste stream (see Makhloufi and Bouadam, 2022). Another example can be drawn from Asia, where Japan passed about eight CDW laws and regulations over a 20-year period including 'Action Plan for Construction Waste Measures' in 1994, 'Construction of by-product Recycling Initiative' in 1997, 'Procurement Law in Construction' in 2001 and the 'Waste Disposal Act' in 2012, where CDW is strongly regarded as a potent environmental threat (Wang and Qin, 2018). It can be argued that laws that are specifically meant for CDW, rather than generic waste laws, are crucial because they ensure maximum concentration, innovation, or resource supply to ensure environmental sustainability. This assertion is corroborated by the high levels of success in recycling (over 75%) of CDW in countries like Austria, Denmark, Germany, New Zealand, etc. (Agamuthu, 2008). Yet in the context of SSA, countries rely on generic waste laws that classify CDW as general waste that does not pose an immediate threat to the environment.

To illustrate the above, South Africa relies on the National Environmental Management Act (Act No. 107 of 1998) which classifies CDW as an insignificant threat to the environment, and therefore is generally permitted for landfilling without treatment. The same can be said of countries like Burkina Faso and Nigeria, where CDW does not meet the prescribed criteria for recycling (Ajayi et al., 2008). The failure of CDW to meet the so-called recycling criteria is unique to the SSA region, and the effect of this classification is that it results in cases of illegal dumping or indiscriminate disposal in landfills. Furthermore, CDW cannot be considered general waste because of its large size, lack of malleability, and often, the hazardous nature of its airborne constituencies (Agamuthu, 2008). Categorization as general waste means that CDW is not a priority waste stream despite its well documented poor environmental performance (e.g. Rohracher, 2001; Ajayi et al., 2008; Ametepey and Ansah, 2014). Critics of environmental law have argued that South Africa suffers from fragmented legislation in the sense that there are several laws that relate to similar problems without delineating responsibilities clearly (Zhakata et al., 2016).

An additional challenge affecting sustainable CDW management in SSA is that of strong political interference in municipal processes. This is largely unique to the SSA region because of the widespread centralisation of power and vengeful political processes. This can be illustrated by a Zimbabwe case study where thousands of 'illegal' structures were demolished across Zimbabwe in what was termed 'Operation Murambatsvina' or 'Operation Clean Up' (Sokwanele, 2005; Madebwe & Madebwe, 2006). While on paper the initiative was meant to 'clean up' Zimbabwe, critics argued that the operation was motivated by the electoral defeat of the ruling party in Zimbabwe in the urban areas by the opposition party (Sokwanele, 2005). The process was conducted hastily and abruptly without a plan on how to manage the resultant demolition waste (see Madebwe & Madebwe, 2006). While Zimbabwe did not have circularity measures at the time, the opposition-run municipalities depended on landfilling for CDW management. Interference in municipal processes during the 'clean up' campaign led to thousands of tonnes of demolition waste randomly placed across Zimbabwe (Madebwe & Madebwe, 2006). Another example can be drawn from South Africa, where some government officials interfere in municipal decision-making processes which leads to a "lack of perceived authority to act by waste staff" (Godfrey et al., 2013, p.298). It is argued that some politicians deliberately frustrate certain initiatives because they do not provide favourable political optics on the ground (Godfrey et al., 2013). When analysed closely in the context of CDW management, political interference in municipal processes impedes the ability of waste staff to affect sustainable initiatives.

Another barrier to sustainable CDW management in SSA is the apparent shortage of funds (e.g. Godfrey et al., 2013). It can be argued that a shortage of funding undoubtedly disrupts sustainable waste management in SSA countries, but it is not unique to the region. Shortage of funding has been reported in countries such as India (The Times of India, 2018), Brazil (De Oliveira et al., 2022) and Cambodia (Singh et al., 2022). In all these cases, a lack of funds to finance waste management projects and plans causes massive pressure on local government's ability to deliver service. Further investigation however reveals that while the issue of a lack of funding is widespread and significant, what is unique about it in the context of SSA is that even though claims for shortage of capital are common, salaries of municipal officials have increased dramatically in the last decade (Godfrey et al., 2013). This casts some doubt on the claims of shortage of funding but rather suggests low prioritization of effective service delivery due to greed or corruption.

**Table 2.1. Summary of barriers affecting CDW management in SSA**

| Location: Sub Saharan Africa | Associated barriers to CDW Management |
|---|---|
| 1. | Lack of circular economy initiatives to minimise CDW. This is worsened by the lack of skilled/ competent personnel. |
| 2. | Poor recruitment strategies by local authorities. It is common for incompetent or unqualified people to be hired for important positions. |
| 3. | Top-down management approaches adopted by local authorities excludes important stakeholders such as local communities. |
| 4. | Lack policy tailor made for CDW management. |
| 5. | Political interference in municipal processes disrupts effective and timely decision making. |
| 6. | Poor funding of municipal processes which results in poor implementation of strategic initiatives. |

## 2.5. Framework for sustainable CDW management in South Africa

The construction sector will continue to expand rapidly in the foreseeable future in the Republic of South Africa just like in most SSA countries, due to population growth and economic expansion. Drawing from this perspective, it is apparent that there is a need for urgent practical solutions to curb unsustainable CDW waste management barriers which often lead to practices such as dumping or landfilling. In the absence of cutting-edge methodological transformation to CDW management, the linear approach currently adopted in the construction sector will continue to generate vast quantities of waste, and further destroy the environment in search of virgin materials. It is noteworthy to mention that the challenges facing CDW management in SSA are generally similar because systems and processes in waste management are related. However, South Africa is somewhat unique to the rest of the sub-continent because policy (although it needs further improvement and implementation) and waste management infrastructure are generally available although it spreads across public and private entities (see Rasmeni & Madyira, 2019), whereas other countries in SSA such as Zambia, Nigeria, and Tanzania lack these infrastructures (e.g. Agbesola, 2013; Sakanyi & Kooma, 2022; Mbwilo & Mahenge, 2022). It is on this basis that this section proposes an agenda for sustainable CDW management in South Africa, although the suggested solutions can also be bent to suit other SSA countries.

One of the solutions to lessen the barriers associated with CDW management in the South African context is to transition to a science and technology waste governance infrastructure that is internet-based. However, it must be noted that there are some challenges, particularly in rural areas, with internet connection in South Africa. Yet, despite this situation, the urban areas where most CDW is produced are well-connected (especially in comparison to other SSA countries) so that any internet-based platform can be effectively utilized. The construction sector can immensely benefit from this situation to transform communication systems in the industry. It has been hinted in the preceding section that communication and data-sharing constitute a critical component in achieving an effective CDW management agenda in any context.

Therefore, there is substantial need for the creation of an online-based platform (e.g., a database) where both small and major construction projects in each city can be listed. Within this platform is listed the types and volumes of CDW and the associated location. For effective operation of the online platform, it should be equipped with global positioning systems (GPS) algorithms to assist with navigation to construction sites. The purpose of this platform would be to ensure the adoption and success of circularity in construction, such as the reuse or recycling of CDW.

The success of the proposed online platform is dependent on the adoption of a co-management strategy that features various crucial stakeholders. Solid waste management studies in the context of South Africa suggests that there is an ineffective top-down management style where important decisions are imposed from the top while effectively side-lining important stakeholders (e.g. Kubanza & Simatele, 2019). To shift from a top-down management style in waste management, stakeholders such as ICT specialists, construction companies, local municipalities, state and municipal police, non-governmental organisations (NGOs), and local communities could be involved in CDW management planning. Regarding the proposed online platform, ICT specialists are crucial for the design and maintenance of the online platform, and for making it user-friendly to all interested parties to eliminate potential frustration for users. The role of local municipalities in this online community is to oversee CDW management processes and regulate activities, particularly during onsite waste processes and the transportation period.

The NGOs, as discussed in the earlier section, these organisations play a significant role in waste management processes in SSA countries (including South Africa) due to the inadequacies associated with local and national authorities. In this case, the role of NGOs could be that of financing the creation and maintenance of the proposed online platform, because municipal funds are surrounded by bureaucracy and other disruptive politics. NGOs can further complement the work of local municipalities in CDW management by encouraging segregation of CDW onsite and making it suitable for reuse or recycling rather than for landfilling. NGOs can achieve this through deployment of paid 'green scorpions' or trained waste management officials at major construction sites.

To ensure the success of this proposition, NGOS need to be aware of the location of construction or demolition sites in each area, and with its GIS-based location algorithms, the significance of the online-based platform is immediately apparent. Furthermore, to enforce local and national environmental laws, municipal and state police could be deployed along the channels typically used for transportation of CDW from construction sites, and the online platform could assist in coordinating this.

In addition to the above proposition, it is important to highlight that research on solid waste management in South Africa have emphasized the significance of the participation of local communities in solid waste management processes (e.g. Kubanza, 2021). To reduce the barriers to CDW management in South Africa, it is argued that local communities can be involved through an incentivized programme where community members can salvage materials at construction/demolition sites or landfills for resale or reuse. This initiative already exists in South Africa, but it focuses largely on plastic waste. Adopting this strategy for CDW would be useful in terms of minimising resource extraction from the environment, waste reduction, and saving landfill space while creating the much-needed employment in South Africa. Furthermore, the use of local communities in CDW management can have an effect of complementing ineffective waste management systems in South Africa by eliminating illegal dumpsites, which are mostly located in low-income areas.

Another strategy that can be deployed to eliminate CDW management problems in South Africa is by engaging institutions of higher learning like universities and colleges offering construction or architecture courses because there is a widespread shortage of expertise in sustainable practices across the sector (Godfrey & Nahman, 2007; Laubscher, 2012). It is important to note that achieving sustainable CDW management cannot be done overnight, and therefore, short- and long-term solutions should be encouraged. To tackle the long-term problems, it has become crucial for higher learning institutions in South Africa to offer construction-related courses to introduce aspects of circularity in the field. For example, waste minimization can be achieved in the design stage of architectural plans, throughout the construction phase, and lastly, the demolition stage. The technical expertise required to achieve this can be offered by institutions of higher learning such as universities and colleges. Furthermore, universities can play a crucial role in the design of durable or reusable construction materials to minimize waste at the end-of-life phase of buildings. It is important to note that 'design for durability' or for 'reuse' is rapidly gaining traction in developed countries, and its adoption in a South African context can offer significant environmental advantages. To achieve short-term CDW management solutions, institutions of higher learning can provide onsite training or workshops for construction project managers and their teams on waste management strategies. While such a solution is not unique to South Africa, it is currently not used in the region, and therefore it would offer important environmental benefits.

Finally, a considerable body of literature in the last two decades has emphasized that the construction sector must transition to more sustainable methods of demolition (Dantata et al., 2005). Chief among the recommendations is advocacy for the adoption of systematic demolition which is called 'deconstruction' (Dantata et al., 2005). Deconstruction avoids razing structures unsystematically to create unrecyclable or unsalvageable demolition waste which would end up in landfills (see Bertino et al., 2021). By following a systematic way of demolition, deconstruction minimizes the amount of atmospheric pollution from fugitive dust during the destruction stage. Furthermore, deconstruction ensures that vast quantities of material is saved (Bertino et al., 2021), and therefore can be used for its originally intended purpose, rather than just used in upfilling of foundations. South Africa currently depends mostly on landfills for the disposal of CDW (Bester et al., 2017), and therefore, deconstruction would present significant waste management benefits. However, deconstruction is associated with high expenses and lengthy periods, which is unpopular in construction (Dantata et al., 2005). This is particularly problematic in the context of a developing country like South Africa because of funding deficiencies. To eliminate this problem, it is recommended that the government of South Africa can initiate some incentives such as financial subsidies, or supply of equipment and specialised manpower at major demolition sites. This approach to CDW is crucial in achieving sustainability in construction.

### 2.6. Conclusion

With the rapid expansion of the construction sector in the SSA region, there is a significant rise in the amounts of CDW waste, particularly across the major cities where much of infrastructural development occurs most. The expansion of the construction sector provides a great number of benefits to the region in terms of employment, infrastructure, and beautification of cities among other things, and yet, there is a plethora of barriers affecting the management of the associated CDW. This review paper has uncovered a lack of balance in SSA between urban infrastructural development and or sustainability in waste management. Although several CDW management barriers seen in the context of SSA can also be found in other regions of the world, the study area stands out in several ways that have been discussed. The major reasons include centralisation of funds, massive political interference, and salary-related corruption among others.

With a global call for more sustainable CDW management due to climate change, there is an urgent need to formulate strategies to counter the barriers to CDW, and this study has suggested several measures to achieve this. The region requires a shift from generic waste laws which typically classifies CDW as general waste. The classification of the environmental performance of waste materials cannot be judged only based on toxicology, because several other attributes such as ubiquity and physicality can significantly affect different components of the environment. Based on this, the SSA region requires tailor-made laws for waste streams such as CDW to achieve high levels of sustainability such as in Europe and Asia. As the article has highlighted, barriers to CDW can further be reduced through the participation of universities and various other stakeholders such as local communities, municipalities, police, and construction firms among others in environmental management. An innovative online communication tool offers opportunities to share data and information on CDW among all stakeholders, and ultimately, it contributes to sustainable environmental management.

## 2.7. Knowledge gap

This chapter presented a discussion of extant literature on the barriers affecting CDW management in the context of developed and developing countries outside of SSA. The chapter also discussed the barriers to CDW management in the context of SSA with a bias to South Africa as a case study of this study. It is found that CDW management remains a major problem in many parts of the world for several different reasons. In the context of developed countries, the main barriers to effective CDW management include poor governance systems where decentralization of legislative power means that multiple waste management legislations are promulgated at state or provincial level. The problem with this approach to waste governance is that it becomes problematic to meet national and international environmental management milestones because states may have different aims and objectives. However, this chapter also revealed that effective construction and demolition waste is also hindered by the lack of trust in the quality of recycled aggregates by the construction sector. The failure to accept recycled aggregates means that the circular economy and its principles of 'reduce', 'recycle', and 'reduce' will not be realised in the sector, causing continued generation of waste. Although this is a huge barrier to CDW management in developed countries, this chapter also revealed that poor communication between stakeholders in the construction sector across developed countries leads to increased waste production because building plans often change during the construction phase. Change of building plans during construction means that sections of a structure are demolished to make way for desired features, causing further production of waste materials. Finally, poor CDW data collection is also common in the construction sector, which affects the quality of waste laws. This is a serious barrier to CDW management because effective waste management depends largely on strong legislation.

In the context of developing countries outside SSA, this chapter reveals some similarities with problems in developed countries. For instance, weak waste laws or poor law enforcement is a common problem in developing countries just as it is in developed countries (Alotaibi et al., 2019). This is a significant barrier to CDW management because it leads to widespread illegal dumping, although this is a much bigger problem in developing countries (Mahayuddin et al., 2008). Another similarity is the lack of commitment to the circular economy approach to waste management. However, unlike in developed countries, the construction sector in developing countries out of SSA generally disregards the circular economy because aspects like separation of heterogeneous waste require large capital and labour investment. For many construction companies, this is an expensive venture that can be avoided by disposing of waste in landfills. Other barriers to effective CDW management in developing countries emanate from fragmented management systems, where multiple actors including municipalities and private entities participate in waste governance. As this chapter revealed, this system of governance is weak where no clear delineation of responsibilities is present such as in developing countries in Asia, South America, and parts of Europe. This leads to neglect of duties on the pretext that other stakeholders can perform the outstanding responsibilities.

In the context of SSA, the problems are largely like those in both developed and developing countries across the world. However, these problems appear to be more widespread and multifaceted in the SSA region, where they can be classified as financial, administrative, and political problems. Regarding the financial problems, the SSA region is characterized by a chronic shortage of skilled labour to enforce circular economy initiatives. This problem arises from the fact that many skilled workers prefer to work in the private sector where remuneration is better, thereby causing massive waste management problems in the public sector. Other than this, CDW management is also affected by political problems where the disbursement of municipal funds by the national government is replete with delays due to political red tape. As the chapter revealed, these delays often cause disbursement of funds even at the end of a fiscal year rather than at the beginning. The major problem with this is that effective CDW depends on the availability of funds. While this is a major problem on its own, the situation is worsened by poor legislation where the generic waste laws classify CDW as a small threat to the environment. This classification of waste is based on the traditional view of environmental risk of waste through presence of toxins or toxicants. Ultimately, such a narrow view of waste motivates indiscriminate landfilling or illegal dumping. Finally, from this chapter it is revealed that effective CDW management is caused by some administrative issues such as poor recruitment practices. Corruption and nepotism in many SSA countries like South Africa cause the recruitment of unqualified personnel, causing massive disruption of service delivery and resulting in among other things, poor CDW management.

It is apparent from the discussion in this chapter, global CDW management remains permeated with problems that challenge the concept of environmental sustainability. Much has yet to be done from a studies perspective to solve the challenges that affect waste management in the construction sector, particularly in developing countries like South Africa. While this literature presents critical knowledge on the state of CDW management, particularly in the SSA region, it fails to provide sustainable alternative methods to effectively manage CDW. This is a serious flaw especially in a period where population continues to grow. Studies on population dynamics in SSA suggest that the entire region is experiencing massive growth and by 2050 the population will reach approximately 2.12 billion (UN-DESA, 2019). The growth of human population influences the expansion of the construction sector to meet the rising demand for the built environment. While the growth of the construction sector represents an expansion of the economy which is desired by countries, it also means the production of high volumes of CDW which can be detrimental to the wellbeing of the environment. Studies that focus on ways to effectively and sustainably manage CDW become immediately apparent. This is especially the case in South Africa, where massive construction projects can be observed throughout the country, especially in the major cities that are currently experiencing inward migration for economic purposes. In recognition of the studies gap highlighted in this section, Chapter 3 focuses on the methodological approaches to CDW management in the context of South Africa to proposing an effective and sustainable method of managing the waste stream.

**Table 2.2. Outline of research gaps in CDW management in South Africa**

| Point | Gaps in knowledge |
|---|---|
| 1 | No studies focusing on the environmental performance of CDW outside the lens of toxicity |
| 2. | Limited studies on the environmental performance of inert CDW in aquatic ecosystems such as wetlands despite the widespread dumping and infilling. |
| 3. | Lack of studies focusing on how best to effectively manage CDW in South Africa and developing countries at large. |

# CHAPTER THREE

# METHODOLOGICAL CONSIDERATIONS

## Overview of the chapter

This chapter is made up of a paper that is under consideration for publication in a peer-reviewed journal. The significance of this chapter is to provide an overview of the methodological considerations of construction and demolition waste (CDW) management. Two kindred methodological approaches of the 'Circular Economy' (CE) and 'Industrial Ecology' (IE) are uniquely amalgamated to improve CDW management in the context of South Africa. A number of scholars argue that the CE is a crucial approach to sustainable waste management because it aims at reducing pressure on the environment (Heshmati, 2015; Rizos et al., 2017; Abad-Segura et al., 2020). Similar arguments have been put forward in the advancement of IE (den Hond, 2000; Roberts et al., 2004), which underscores the significance of the approach to achieving environmental sustainability. While these arguments are largely accurate in the context of developed countries where technologies and waste management funding are available, the same cannot be said of developing countries like South Africa. However, it is argued that the two concepts of CE and IE can be attuned to the social, economic, social, and technological realities of a developing country to produce an effective methodological approach to CDW management.

The paper critically discussed the different methods and approaches to CDW management across the world with a specific focus on South Africa. The methods deployed for CDW management can be classified, namely sustainable and unsustainable methods. There is only one sustainable method, namely the CE, which is practiced in several ways, among them Building Information Modelling (BIM), Design for Deconstruction (DfD), and Deconstruction. On the other hand, unsustainable methods include illegal dumping, reactive remediation, and landfilling. Although the sustainable approaches to CDW management have the potential to reduce pressure on the environment through dumping or extraction of raw materials, it is generally untenable in developing countries like South Africa in the same form deployed in developed countries. In the conclusion of the chapter, it is therefore argued as previously stated, that CDW management in South Africa can be improved through an amalgamation of CE and IE in a way that factors the social, economic, political, and economic realities of the country.

## Paper No. 2

## An application of the Circular Economy and Industrial Ecology as Methodological Imperatives for the Sustainable Management of Construction and Demolition Waste in South Africa.[2]


### Abstract

In the 21st century, sustainability has become the cornerstone of the global economy due to rapid environmental degradation and extreme climatic events. Researchers, policymakers, global institutions, and environmentalists across the world have intensified calls for a transition to environmentally friendly waste management methods to reduce pressure on the environment. However, although many sustainable practices have emerged in the major sectors of the world economy such as construction, to reduce its destructive and consumptive nature, many of the methods are largely unsuccessful, particularly in developing countries. This study was carried out to assess the methodologies and approaches to construction and demolition waste management across the world, to propose a suitable approach for developing countries, using South Africa as a case study. This was carried out using a systematic literature review, semi-structured interviews, and questionnaires, with epistemic communities in the construction and environment sector. The major outcome of the study is that most approaches deployed in construction and demolition waste management are highly effective in developed countries where they originate but fall short of similar efficacy or usability in developing countries. It is argued that methods emerging from developed countries cannot be deployed in the same form in developing countries such as South Africa but rather should be amended to suit certain economic and technological realities. To improve construction waste management in South Africa, it is proposed that a hybrid of circular economy and industrial ecology can offer an effective way of managing construction and demolition waste.



**Key words**: Environment, Sustainability, Construction and demolition waste, Circular Economy, Industrial Ecology, Circularity.


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## 3.1. Introduction

Construction and demolition waste (CDW) has in the past two decades emerged as a potent source of global environmental concern, which causes major anxieties among researchers, environmentalists, and policymakers (European Commission, 2008; Ohemeng & Ekulu, 2020; Zhang et al., 2023). Scholarly studies in the last two decades have consistently argued that CDW is the most voluminous waste stream, comprising between 35 and 40% of the global annual waste output (Tam et al., 2010; Papargyropoulou et al., 2011; Ginga et al., 2020; Zighan & Abualqumboz, 2021). High volumes of CDW are a testament to the resource intensiveness, wastefulness, and environmental disruption of the global construction sector. Extant literature on construction reveals that, apart from the above-stated characteristics of the waste stream, it also contains 'forever' contaminants that can linger in the environment in geological timeframes, causing damage in deep time (e.g. Muigai et al., 2013; Chamberlain et al., 2022). Furthermore, even the inert components of CDW which are largely non-biodegradable can also linger in the environment in geological timescales (e.g. Bharadwaj et al., 2015; Karthikeyan et al., 2020). Based on this wide range of environmental problems, there has been a rise in scholarship that discusses various methodological approaches deployed to manage CDW across the globe.

A synthesis of extant literature shows that methods deployed in the management of CDW fall into two broad categories. The first group of methods tends to be preventive, focused on a fundamental goal to avert, reduce, or rematerialize waste before, during, and after the construction phase (Bunz et al., 2006; Purchase et al., 2022; Zhang et al., 2023). Methodological approaches belonging to this category are generally motivated by the global call to transition to a cyclic economy where 'zero waste' or 'net zero' environmental themes are central. This category generally comprises methods that are powered by cutting-edge technologies, and typically emerge in developed countries of the Global North where the bulk of machinery and concepts are generated or conceptualized (Chen et al., 2017).

The second group of methods encompasses approaches that are linear in nature (see Hoornweg & Bhada-Tata, 2012; Rondinel-Oviedo, 2023). These methodological approaches are motivated by maximization of profits, and they engender two main problems. They are predominantly associated with environmental crimes, and they tend to generate massive pollution, and disrupt ecosystems (e.g. Fitchett, 2017; Mangoro & Kubanza, 2023). Ultimately, the methods belonging in this category result in heavy sedimentation of terrestrial and aquatic environments due to either repeated deposition or erosion by surface run-off over extended periods. Linear methods of CDW management are the direct opposite of cyclic approaches because they are not aimed at preventing or rematerializing materials, but at discarding them and extracting virgin resources from the environment.

Although the world is increasingly globalized and countries exchange ideas, concepts, and technologies at a faster rate than before, there appears to be a dichotomy in the rate of adoption or success of environmentally sustainable methodological approaches to CDW management. This dichotomy appears to be largely motivated by technological and economic disparities between developed and developing countries. To better understand the trends in CDW management methodologies, in the following section a synopsis of the current methods and approaches to CDW management across the world is presented. This synopsis is conducted to identify the weaknesses in the current methods of CDW management across the globe, and ultimately present a suitable approach for South Africa.

### 3.2. An Analysis of Current Methodologies and Approaches to CDW Management across the Globe.

The construction industry across the global economy faces massive and sustained amounts of pressure from governments, policymakers, and environmentalists to sustainably manage CDW. In response to the growing pressure, the construction sector has developed several methods that tend to be commensurate with economies in each region. However, due to globalisation and the rapid exchange of ideas, the global construction sector now generally deploys homogenous methods of CDW management but with varying success. The most adopted methodological approach is the deployment of a closed-loop system called the circular economy (CE), which is based on three main principles namely to 'reduce', 'recycle', and 'reuse' waste materials (Korhonen et al., 2018; Velenturf & Purnell, 2021; Langsdorf & Laurens, 2022). As the three principles suggest, the CE is aimed at limiting waste materials, and this has been achieved with notable success in developed countries such as the

Netherlands, Denmark, Germany, and the United Kingdom, with recycling rates ranging between 50 and 90% (European Commission, 2008; Kern et al., 2015).

Other regions of the world such as Asia, America, and SSA have also attempted to deploy the CE for CDW management. In the first two regions, the strategy has been deployed with an average degree of success in major economies such as Malaysia and the United States of America (e.g. Omar et al., 2022; US-EPA, 2023). In SSA however, the application of the CE approach in construction has failed and attempts to transition to the closed loop system suffer from political and economic factors. For instance, although the concept has been adopted through the 'waste management hierarchy', the construction sector in the region generally discredits the quality of recycled aggregates (Kearsley & Mostert, 2012; Aboginije et al., 2020). Furthermore, studies argue that the SSA region lacks the required capital investment to purchase, maintain, or operate recycling technologies acquired from developed countries (e.g. Kubanza et al., 2017; Global Green Growth Institute, 2019; Al-Otaibi et al., 2022). This situation suggests that the application of CE in the SSA construction sector remains a tentative methodological approach, thus linear strategies are further encouraged. This trend is likely to continue because studies in the last two decades suggest that heavy-duty recycling machinery for CDW costs an approximate equivalent of US$274 000 to $844 000, depending on the capacity and capabilities of the plants (Nunez et al., 2007; Zhao et al., 2011). Therefore, while the CE appears to be a success in developed countries, the cost of the machinery required to achieve industrial-scale recycling is financially unsustainable for the persistently underfunded municipalities across SSA.

Studies on the concept of CE shows that it is applied through several different approaches. Studies emerging in Europe show that the construction sector in that continent has started to adopt the 'Building Information Modelling' (BIM) approach (Hardin & McCool, 2015; Won et al., 2016). The BIM approach is a facet of the CE which addresses the principle of waste 'reduction' in the design stage of buildings using 3D modelling, and studies have revealed that it reduces CDW by approximately 4.3% to 15.2% (Won et al., 2016). The BIM approach achieves this by reducing the frequency of reworking some sections during the construction phase (Hardin & McCool, 2015). Studies has demonstrated that builders are often forced to rework some sections on recognition of a fault, and this generates volumes of waste. The BIM method prevents this from happening. Second, the BIM approach reduces potential conflicts among stakeholders, e.g. personnel from various disciplines in construction during the design phase (Krygiel & Nies, 2008). It is important to note that the construction phase of a building often involves experts from many professions such as plumbing, engineering, and architecture. The BIM method eliminates or reduces the potential of conflicts among these experts which may result in design changes during construction. Given this background, it is apparent that the BIM approach to CDW management offers significant advantages in achieving waste reduction in construction. It has been deployed in European countries like Finland, Denmark, and the Netherlands (Charef et al., 2019), while in Africa it is known to have been used in Egypt (Khodeir et al., 2018).

However, the most surprising drawback of the BIM method of waste reduction in construction is that it commands a high level of technical expertise (Kouider et al., 2007). Additionally, it is associated with high cost, especially in short-term projects, and thus many in the global construction sector resist the method (Kouider et al., 2007). These factors mean that applicability of the method in developing countries in SSA and other regions of the Global South will be met with resistance. Because of the high cost and demand for expertise, the BIM method fails to meet the financial and human resource preferences of construction companies in struggling economies. However, the BIM remains a formidable method of CDW management despite the above drawbacks because it is an investment in the end-of-life cycle reuse.

Other studies discuss that 'Design for deconstruction' (DfD) is also an approach emanating from CE to manage CDW. This method is kindred to the BIM discussed prior in that it forms part of the modern building design phase (Kanters, 2018). The DfD approach follows two principles of circularity namely 'reduction' and 'reuse' of building materials. Advocates of the method define it as an approach to waste management where a building is designed in a way that allows adaptation, renovation, and reuse of construction inputs (Kanter, 2018). Although some studies advocate for 'deconstruction' to salvage building materials and minimize waste as shall be discussed, the method is not particularly effective where construction inputs were designed to be permanent (see Bertino et al., 2021). The DfD approach facilitates easy retrieval and reuse of construction materials, ultimately meaning that the energy used in manufacturing is retained, while greenhouse gas emissions and pollution are reduced (Akinade et al., 2017). This method has been used in Central Asian countries like Kazakhstan and Uzbekistan (Tleuken et al., 2022). Additionally, the DfD has also been deployed in Canada with high success (Pulaski et al., 2004) and in the United Kingdom (Yakubu, 2023). The major setback with this method is that there is a lack of availability of suitable materials to achieve DfD. Additionally, designers face challenges integrating the DfD concept into buildings since they lack freedom and control over the construction project schedule (Rios et al., 2015). Therefore, while DfD offers potential CDW management advantages in theory, in practice, the lack of availability of materials designed for deconstruction renders the method generally inapplicable.

In addition to the methods discussed prior, others in the construction sector deploy the deconstruction approach to take down buildings as opposed to demolition (Ahmad & Anigbogu, 2010). Proponents of this approach define deconstruction as a planned, systematic and selective dismemberment of a constructed structure for purposes of recovering a maximum quantity of reusable and recyclable materials in a cost-effective way (Bradley, 2006). The process of deconstruction of buildings ensures that materials are separated rather than randomly mixed as is the demolition case. Thus, deconstruction meets all three principles of circularity by enabling the reduction, reuse, and recycling of materials. Conceptually speaking therefore, the definition of 'deconstruction' suggests that the method is environmentally friendly and highly cost-effective, making it enticing for any construction company. The method has been applied in developed countries such as the United States of America, Canada, Australia, and Japan (Kibert et al., 2001; Chini and Bruening, 2003; Creba, 2019). It has also been deployed in developing countries like South Africa and Zambia (Gibberd, 2020), while literature is scarce in Asia and Latin America.

Yet deconstruction is doubted by some studies for the same reasons that DfD is criticised (e.g. Bertino et al., 2021). Critics argue that most buildings were constructed to be permanent, and therefore the majority of the materials used, along with the building methods (e.g. reinforcement) means that materials cannot be successfully salvaged through any method (Bertino et al., 2021). Other sceptics condemn deconstruction because where there is a lack of skill e.g. in South Africa, it is done chaotically, resulting in large quantities of waste which the method was originally designed to reduce (Gibberd, 2020). Another noteworthy study, which uses a case of Massachusetts in the United States of America, found that deconstruction incurs higher costs than traditional demolition by up to approximately 14 to 20% more (Dantata et al., 2005). Such a high number of challenges associated with this approach renders it highly unattractive to the global construction sector, particularly in countries like South Africa, where fresh building material is affordable, and where illegal dumping is a highly adopted method of managing CDW.

Several challenges associated with various approaches to CDW management continue to challenge the idea of green construction. Yet these problems are further compounded by a negative attitude of the construction sector and some governments towards sustainability in construction. This problem is evident in countries like Nigeria and Zimbabwe, where construction personnel does not place priority on waste minimisation (Madebwe & Madebwe, 2006; Albert et al., 2021). In Nigeria, there is perpetual poor handling of waste at construction sites, which leads to the rapid generation of waste (Albert et al., 2021). In Zimbabwe, the government is consistently involved in demolition activities without a solid plan for waste management, resulting in widespread illegal dumps of CDW (Madebwe & Madebwe, 2006). It can be argued that the negative attitude to CE and related initiatives reduces the likelihood of success of the approach in construction.

Despite the challenges associated with the closed-loop system of waste management in construction, it remains an environmentally sound approach, particularly in comparison with linear methods. Linear approaches which encourage 'take', 'make', and 'dispose of' materials are commonly used in developing countries and less often in developed countries. The most used linear method is the practice of landfilling (e.g., Barnes, 2016; Ulubeyli et al., 2017; Aboginije et al., 2020; Mogodi & Otieno, 2021), and countries that deploy this approach include the United Kingdom (44%), United States of America (29%), Bulgaria, and South Africa (Hadjieva-Zaharieva et al., 2003; DEFRA, 2013; Simelane, 2017). On one hand, landfilling is affordable for most construction companies, especially in developing countries, yet on the other hand, it is an environmentally unsustainable approach because CDW rapidly takes up space (Aboginije et al., 2020). This is particularly problematic because many countries the world over are fast running out of landfill space. Given these realities, in the absence of fresh and more sustainable methodological approaches, CDW management will cause major problems, not only to urban managers but also to the physical environment.

Kindred to the landfilling method is the practice of illegal dumping, mostly in locations such as roadsides, open spaces, and wetlands. This approach to waste management is common in many countries across the world where law enforcement is often weak and uncoordinated. Studies have documented cases of massive illegal dumping in countries like South Africa, Italy, China, and Pakistan (Euronews, 2015; Simelane, 2017; Danni, 2019; Du et al., 2021). Other reasons accounting for illegal dumping includes exorbitant disposal fees and shortage of landfills, and this is particularly the case in African cities such as Johannesburg (e.g. Simelane, 2017). In comparison to landfilling, the practice of illegal dumping presents major environmental problems, especially when it is performed in wetlands. The effect of direct disposal in water bodies is that it can result in throttling and floods, and this has precedence in some parts of the world such as China and South Africa (Danni, 2019; Mangoro & Kubanza, 2023). In Europe, dumping in water bodies is often legally protected. For example, dumping in water bodies is often allowed in Ireland, resulting in the complete disappearance of wetlands or contamination of aquatic species (Staunton et al., 2015). Therefore, although the approach to CDW management through dumping offers significant financial incentives to perpetrators, it is environmentally unsustainable.

### 3.3. Data Sources and Materials

This paper serves to establish a hybrid methodological approach to CDW management in the context of SSA, using South Africa as a reference point. Extant literature in the recent two decades has emphasized that many SSA countries lack consistent, rigorous, and traceable methodological approaches to CDW management, resulting in massive dumping and persistent onslaughts on the environment for the extraction of virgin materials for construction. To gather the information informing this study, a twofold data collection strategy was adopted.

### *3.3.1. Literature Review*

First, this study was informed by a systematic review of extant literature on CDW management on a global, regional, and local scale (South Africa). This review of literature is imperative because it provides an opportunity to grasp the dynamics involved in CDW management globally, and this could be profitable in the establishment of an effective approach for developing countries like South Africa. Literature informing this study was ultimately derived from several online public access catalogues (OPACs) including Science Direct, Web of Science, and Jstor. OPACs constitute an effective tool for gathering peer reviewed literature because they are linked to a variety of peer reviewed scholarly journals. Considering that OPACs provide a large body of literature across a broad spectrum of disciplines, several search phrases containing Boolean Operators were deployed to gather relevant literature. The key search phrases included construction AND demolition waste, construction OR demolition waste, construction NOT household waste, methods OR techniques in construction AND demolition waste. A search for literature from the above-stated OPACs yielded 102 articles. Additional literature informing the study was derived from online newspapers and websites from a global perspective.

### *3.3.2. Empirical data*

To gain a comprehensive understanding of the current methods used to manage CDW in South Africa, a questionnaire survey and interviews were deployed among the experts from non-governmental organisations, construction firms, and municipal and provincial government bodies in Johannesburg and the Gauteng Province at large. Broadly speaking, the experts fell within the fields of construction project management, municipal and provincial environmental management affairs, and environmental conservation. The recruitment of participants from the above-stated organisations was useful because CDW is not only involved in construction, but it is also derived from and ultimately discarded into the environment, generating massive disruptions of natural systems. Using a combination of purposive and snowball sampling techniques, 45 experts (n=45) were recruited to participate in the study over 6 months, between 2022 and 2023. Of the 45 experts, 15 (n=15) were recruited from NGOs, 20 (n=20) from construction firms, 4 (n=4) from the

Johannesburg Municipality, and 6 (n=6) from the provincial and national environmental management departments. Furthermore, from the 45 participants in this study, 15 were interviewed in person while 30 participated through a questionnaire survey.

A combination of purposive and snowball sampling methods was used to recruit participants for this study. The first step involved identifying persons occupying managerial positions in the organisations selected for the study, and this was achieved through a rapid search on the associated websites. Once this purposive sampling strategy was completed, the identified participants (n=15) were invited to participate in the study and were additionally requested to recommend potential respondents working in construction or environmental management and conservation. The process of snowball sampling produced 30 (n=30) other participants across all the organisations. Since some participants could not avail themselves for face-to-face interviews, the meetings were conducted virtually (Zoom, Microsoft Teams, and telephonically). Specifically, 10 participants were interviewed via Zoom, 7 via Microsoft Teams, and 9 via telephone calls while the rest (19), completed physical questionnaire surveys.

### *3.3.3. Data analysis*

Data analysis followed a twofold process. First, literature informing this study was rapidly appraised and meta-analysed to determine articles that focus on methodological approaches to CDW management. As stated in section 3.2, 102 articles were gathered from the literature search process across OPACs, but it must be noted that only a fraction of them were relevant to this study. To determine which articles were relevant to the study, inclusion and exclusion criteria were developed. All articles focussing fully or peripherally on building waste management in developed and developing countries formed part of the inclusion criteria, while those that focussed on construction, in general, were excluded because they had no bearing on the study. To determine whether articles matched the inclusion or exclusion criteria, a rapid analysis of abstracts, data, and conclusion sections was conducted, and ultimately, 62 articles matched the inclusion criteria. Subsequently, these articles were used to inform the literature review informing this study.

Data collected through virtual means were transcribed into text format without leaving out important information. Once this process was completed, all empirical data were combined and subsequently analysed through thematic analysis. This is a method of analysing qualitative data by generating codes and themes from textual material. Data were presented through several graphical means such as pie-charts and tables.

### 3.4. Results and Analysis

The first set of questions posed in the interviews and questionnaires aimed to unpack the methods used to manage CDW in South Africa. The biggest theme identified in the participant responses was that CDW is managed through legitimate disposal in landfills across South Africa, and this view was shared by all the respondents who participated in the study (n=100%). Use of landfills for CDW management implies the deposition of 'waste' materials in a dumpsite legitimised by a local authority such as a municipality. The concept of legitimate disposal teases the idea of 'correct' handling of waste, and yet, disposal in a landfill simply involves the removal of waste from places of generation to spaces hidden from public view. The challenge with this approach to CDW management is that landfill sites produce massive quantities of greenhouse gas emissions and leachates that can contaminate the soil or groundwater. Furthermore, due to its ubiquitous nature, CDW rapidly consumes landfill space, which necessitates either expansion of existing sites or establishment of new ones.

Further findings from this study suggest that CDW is also managed through illegal dumping in several locations such as wetlands, roadsides, and hidden spaces across South Africa (Figure 3.1). Illegal dumping is the practice of disposing of waste materials in spaces that are not authorised by local authorities, and the key motivation for this activity is to save funds from the high costs of legitimate disposal in municipal landfills. The standard total cost for disposal of CDW in municipal landfills in the context of Johannesburg is equivalent to approximately US$125 per tonne. A clear source of motivation for illegal dumping is immediately apparent where massive construction projects (large volumes of CDW) are involved.

An additional source of motivation for illegal dumping of CDW in South Africa emerges from the shortage of landfills that permit the legitimate disposal of CDW. A statistical analysis of this finding shows that the view was supported by 92% of the participants, suggesting that a shortage of landfills is a major sustainable CDW management problem in South Africa metropolitans. To illustrate this challenge, we draw upon a view shared by a participant who stated that:

*There are few municipal dumps that accept rubble for disposal, and it is an easy way for illegal waste removal companies to make money (through dumping).*

What is particularly concerning about the above view is that it has a multiplier effect on the disposal costs faced by construction companies. To better understand this assertion, we draw upon the case of the City of Johannesburg, where a landfill in the northern areas of the metropolis that accepted CDW disposal was closed off[3]. The closure of this strategic landfill for construction projects in the northern areas of Johannesburg means that companies are forced to spend larger sums of money to transport CDW to landfills in the southern parts of the city.

The view of higher transportation costs is shared by 85% of the respondents in this study, and one participant stated that their construction company spends an equivalent of approximately US$1 700 to US$ 2 800 per month. This finding suggests that the shortage of landfills in the major cities of South Africa is both environmentally and financially unsustainable and requires immediate remediation.

What is particularly interesting about the prevalence of illegal dumping of CDW in South Africa is that the causes are multifaceted yet connected. According to 45% of the participants of this study, the dumping of CDW is additionally motivated by greed to maximize profits. This idea is captured by a participant from a construction company, who was of the view that:

*Companies are not hiring the correct sub-contractors to remove the waste. They just hire cost-effective but not professional companies.*

[3] This view is shared by Simelane (2017) on their study in the City of Johannesburg.

An analysis of this view reveals that there is an intentional effort to clandestinely manage CDW in order to maximize of profits by sub-contractors engaged to transport waste to landfills. However, this could also be motivated by the extreme landfill disposal fees stated earlier. Although sub-contractors can be blamed for advancing the idea of illegal dumping, the problem also arises from the overdependence on third parties for waste transportation and disposal by construction companies.

To better understand the CDW management process, the next set of questions through questionnaires and interviews asked the participants from construction companies who were responsible for waste transportation to landfills. This investigation observed that all the construction companies involved in the study (n=100%) hired third parties (sub-contractors). One participant who had been in the construction sector for 10 years stated that:

*We contract professional disposers, who differ depending on what waste is to be disposed of…*

What stands out from this view is that CDW is a collaborative process, and it is through this network of actors that waste is unsustainably managed. A network of constructors, demolishers, landfill operators, and 'professional' waste remediation organisations is indicative of determined energies to manage CDW through disposal in landfills, and yet such a complex system means that auditing of waste management is difficult to achieve. For example, another question posed to the participants aimed to discover what measures were taken by construction companies to ensure that CDW reached municipal landfills for legitimate disposal. From the responses provided, there seem to be synergy between construction companies and waste transportation firms, because 80% of the informants stated that there is some form of proof that they require. One participant argued that:

*We hire professional parties to do this (collection and transportation) and provide certificates to prove that it (CDW) has been disposed of correctly.*

Although this finding suggests the existence of an organised and effective method or strategy to manage CDW in South Africa, the reality is that illegal dumping is increasingly becoming worse due to rapid urban sprawl and poor waste management practices. Figure 3.1

illustrates the prevalence of illegal dumping of CDW in some parts of Johannesburg, the biggest producer of building waste in South Africa.

**Figure 3.1**: An illustration of widespread illegal dumping in Johannesburg
*Source: Fieldwork & NGOs photo archive (2021 – 2023).*

From the cluster of images in Figure 3.1., it can be observed that illegal dumping of CDW is prevalent in South Africa’s metropolitan cities such as Johannesburg. In Figure 3.1., illegal dumping occurs in wetlands and by roadsides and what is common between these locations is that disposal is easy due to the location of the sites by the roadside. Despite the prevalence of dumping, however, other participants were of the view that CDW is managed through circular techniques. This view was shared by 37% of the study participants. Circularity implies adoption of three measures, namely reduction, reuse, or recycling of material residues generated from anthropogenic activities such as construction.

According to participants who share this view, large volumes of CDW are recycled. These participants’ perceptions are summarised by the view that:

*…the majority (of CDW) is recycled where applicable. However, the process is hampered by the fact that recycling CDW is a time-consuming process.*

What is interesting about this finding is that the concept of environmental sustainability appears to have permeated the South African construction industry, and yet dumping is increasingly becoming a phenomenon in major cities like Johannesburg. Furthermore, circularity in the South African construction industry appears to only refer to recycling. This view is corroborated by the fact that 70% of the study participants from the construction sector argued that they do not participate in any waste reduction activities. Such a bad environmental problem is exacerbated by the fact that some municipalities, e.g. in Johannesburg, are not equipped to achieve circularity in construction. Three officials from the municipality, representing 7% of the study sample, corroborated this view, stating that:

*Those crushers are not working now, but the city is indeed trying to promote the culture of reuse, recycling, and separation at source. There is also a lack of space for the treatment of construction and demolition waste, which encourages dumping.*

The above view suggests that circularity in a broad sense is no longer a novel strategy for CDW management in South Africa. However, the operation and maintenance of recycling machinery presents enormous challenges for poorly funded South African municipalities. Furthermore, the above view indicates that circularity in the sense of reduction or reuse of CDW is a huge challenge for a developing country like South Africa because separation at source is a time-consuming and labour-intensive process that requires large sums of capital investment.

Additionally, there is a prevalence of mistrust of the quality of recycled aggregates by the construction sector in South Africa, rendering circularity a pointless activity in South Africa. The three informants from the City of Johannesburg Municipality capture this view arguing that:

*There is also a challenge that those in the construction industry doubt the quality of recycled construction material. We usually liaise with the Johannesburg Road Agency for them to use crushed material in road construction, but they often lament the quality of these aggregates.*

From the above view, recycled aggregates of CDW in South Africa have no ready market, and there seems to be heavy dependence on some branches of the municipality for the adoption of recycled material. There is a narrow-minded view that recycled aggregates are acceptable only for road construction purposes, and this strategy eliminates the usefulness of circularity. This is because it neglects the original purpose of materials and the energy input involved in the initial production of the materials. Therefore, circularity as a method for CDW management in South Africa remains largely sound in theory but weak in implementation.

South African municipalities also adopt unconventional methods of CDW management in the form of reactive remediation. While reactive remediation is not a scientifically established methodological approach to waste management, it has been deployed by municipalities such as Johannesburg. Reactive remediation is an approach to CDW management that follows dumping hotspots and performs removal of waste for deposition in landfills. It is an approach to waste management that does not seek prevention of illegal dumping, but to remove waste that is already dumped. Analysis of empirical evidence gathered from environmental NGOs that participated in this study reveals that 75% of experts from these organisations knew of reactive remediation as a key method for CDW management in South Africa. Among the notable views of experts from NGOs, one stated that:

*We have engaged the municipality to remove illegally disposed waste and transport it to the designated landfills.*

It can be seen from the above statement that NGOs work closely with municipalities to effectively manage CDW in South Africa. However, this finding also reveals that the municipality lacks strategies to prevent illegal dumping from happening, and instead relies on reactive remediation for waste removal. Since the dumping of CDW in South African cities is a longstanding problem, the continued practice of reactive remediation points to the possibility that local municipalities now have annual budgets set aside just for removal of illegally dumped waste. This suggests that there is a consensus within the municipality that reactive remediation is an effective methodological approach to CDW management. Additionally, although offenders can be fined up to R10 000 if they are caught (City of Johannesburg, 2018), there is limited policing which further encourages environmental crimes such as dumping. This further points to the possibility of heavy dependence on reactive remediation.

### 3.5. Towards the Application of Circular Economy and Industrial Ecology as Methodological Imperatives for Sustainable CDW Management in South Africa.

The current environmental trends, dominated by deteriorating ecosystems, loss of equilibrium, and extreme weather events caused by anthropogenic activities such as construction, require an urgent shift from the linear way of production (take, make, and dispose of) to a more sustainable one. Data and literature informing this study show that CDW management in South Africa typically follows the linear method. Although there is a global call for sustainable economic practices through the United Nations Sustainable Development Goals, there is a lack of scientific studies in South Africa that propose effective and sustainable construction waste management, and this is even though the sector is among the most rapidly expanding in the SSA region. This study draws on the concept of the circular economy (CE), which is founded on three principles namely 'reduce', 'recycle' or 'reuse' waste materials to achieve sustainability. The CE has been used effectively in the global north due to effective policing and presence of cutting-edge technology, which is not found in South Africa and the SSA region.

Despite these technological and policy disparities, the CE can be effectively attuned to the South African realities, especially when circularity has been successfully applied withing clothing in the region. There is an informal, yet organised system, where used clothing items from the global north are exported to SSA and reintroduced in the market. For countries in the global north, this is an effective way of management of textile waste, while in Africa, masses of economically challenged communities benefit from the purchase and use of cheaper clothing items. A similar strategy can be formally and systematically adopted by deploying informal waste reclaimers at landfills to salvage bricks and masonry for sale (meeting the principles of reduction or reuse of waste). The formalisation of the use of reclaimers requires the establishment of a system to effectively manage the enterprise. Figure 3. 2 illustrates a framework that can be adopted to achieve the formalisation of this concept.

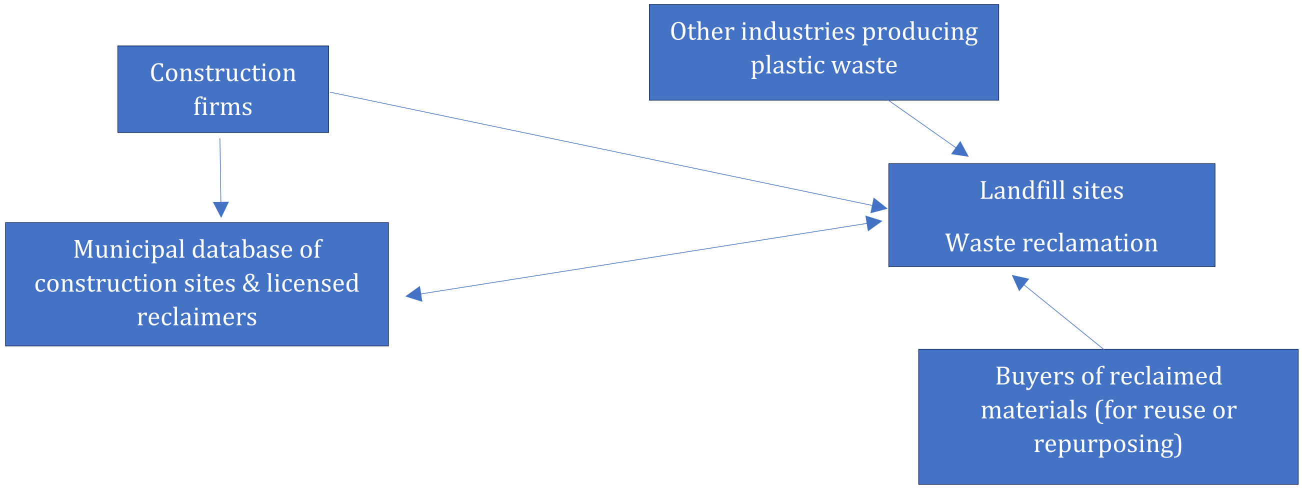


**Figure 3. 2.** Generic model for sustainable construction waste management

*Source: Researcher (2023).*

Figure 3.2 illustrates a model for the formalisation of CDW reclamation at landfill sites in South Africa. From Figure 3.2, it is essential to establish a municipal database comprising licenced reclaimers and construction projects in each major city. This would enable the quantification of construction sites, rendering it achievable to quantify CDW generated in every city. Furthermore, it makes it possible to quantify the amount of reclaimed CDW. In addition to this, having a database of licensed reclaimers is crucial for the management of landfill sites. Landfill sites can be dangerous places because of the haphazard disposal of waste which could collapse on people; therefore, having only a controlled number of reclaimers is crucial for safety and maintaining order.

Informal reclamation of bricks and masonry from CDW is not a novel concept in South Africa. Reclaimers at a landfill in Polokwane City manually retrieve considerable volumes of reusable bricks for resale (Figure 3.3), which is a huge leap in the direction of circularity in construction. The limitation of this approach is that it relegates massive volumes of cementitious mortar and other associated debris into nothing but useless materials. Figure

3.3 illustrates that this material constitutes a significant part of CDW, and therefore, a strategy to rematerialize the waste is essential.

**Figure 3.3 Reclaiming Construction and Demolition Waste at Landfill in Polokwane City, South Africa.**

*Data source: Fieldwork studies (2023).*

To eliminate cementitious mortar and other small construction debris, the concept of Industrial Ecology (IE), kindred to CE, can be deployed as an additional methodological approach to sustainable CDW management. IE unites different industries across the economy by sharing waste materials and transforming them into raw materials for other economic processes (Chertow, 2008). Therefore, instead of downgrading large volumes of cementitious materials as illustrated in Figure 3.3, the material can be further crushed and mixed with tonnes of plastic waste from other industries such as retail and manufacturing to manufacture eco-bricks, paving material, or other products, and reduce dependence on nature for virgin materials. Thus, in addition to reducing pressure on the environment, the proposed approach also reduces costs of construction and creates employment. Table 3.1. summarises the potential benefits of industrial ecology, justifying the significance of adopting this methodological framework.

Table 3.1. Potential benefits of Industrial ecology

| **No** | **Potential benefit** |
|---|---|
| 1 | Reduced consumption of raw materials |
| 2 | Employment creation |
| 3 | Reduced pollution |
| 4 | Saves municipal landfill space |
| 5 | Saves energy involved in sourcing raw materials |
| 6 | Creates synergies between industries and increase resource efficiency |

### 3.6. Conclusion

This study was developed from the need to devise a suitable and sustainable methodological approach to CDW management, with a specific focus on South Africa. To achieve this, a literature review on a global scale was conducted to establish a general view on how CDW is currently managed, and to point out the associated weaknesses or challenges engendered in these methods. In addition to the literature review, a qualitative survey was carried out with experts from the construction industry, non-governmental organisations, and local government institutions, to document the methods and approaches to CDW management in South Africa. This was done with an ultimate view to identify major weaknesses associated with these methods and approaches and devise a suitable approach.

The findings of this study suggests that in theory, South Africa has minimally adopted the concept of circularity in construction with a view to sustainably manage CDW and diminish pressure on the environment. This is through the deployment of machinery for crushing CDW at some landfills. This approach has been deployed with high success in developed countries (50 – 90% recycling) such as those in the European Union (Kern et al., 2015).

However, in the context of South Africa, the transition to a closed-loop system is bedevilled by the inability of municipalities to maintain the machinery, which renders the technology ineffective. Ultimately, the inability of municipalities to maintain the functionality of circular technologies encourages landfilling, and further extraction of raw materials from the environment, and defeats the globally acclaimed concept of green construction. Therefore, while the adoption of CE has revolutionized waste management in construction in developed countries, the applicability of the approach in developing countries like South Africa in the current form remains largely problematic. Extant literature on waste management in developing countries aligns with this assessment, where some studies argue that concepts and methods emerging from developed countries are largely ineffective in developing countries (e.g. Kubanza & Simatele, 2017).

The results of the study further suggest that linear methods of waste management are dominant in South Africa. Linear methods of waste management encourage the 'take', 'make' and 'dispose of' business model, which requires continuous extraction of the earth's finite resources. As the findings reveal, methods such as landfilling, reactive remediation, and illegal dumping are the most used approaches to CDW management in South Africa. Although these methods are also utilized in developed countries, the literature suggests that this is more common in developing countries (e.g. Simelane, 2017; Fitchett & Rambuwani, 2022; Mangoro & Kubanza, 2023). In comparison to the technological approach successfully deployed in developed countries, these linear methods present significant financial benefits to construction companies, or third parties contracted for the transportation of CDW to places of disposal. The dominance of landfilling, reactive remediation, and illegal dumping is further motivated by a breakdown in city management systems, inadequate financing, and other cost-related challenges. This is in sharp contrast to the waste management landscape in developed countries, where processes are controlled by efficient institutions and strong legal systems (e.g. European Commission, 2008). It is from this perspective that this paper argues for a unique and tailor-made methodological approach to CDW management in South Africa, rather than depending on systems that are tailor-made for developed countries. The approach will ideally be based on an amalgamation of the concepts of industrial ecology and circular economy as argued in this paper. Even in cases where recycling is achieved, some in the South African construction sector remain doubtful of the quality of the recycled aggregates, which further attests to the invalidity of the Western methods in developing countries.

Based on the findings of this study, it is argued that South Africa could benefit from a hybridized approach to CDW management to achieve sustainability. An amalgamation of two kindred approaches of Circular Economy and Industrial Ecology, with tailor-made modifications, could provide tangible financial and environmental benefits to CDW management in South Africa. Informal waste reclamation is a rising economy in South Africa, although it is largely carried out with regular municipal waste (Samson, 2020; Ramelelle, 2022). The rise of informal waste reclamation could be successfully harnessed to 'reduce', 'recycle', or 'reuse' CDW at South African landfills. To achieve this, several informal waste pickers could be registered by municipal authorities to reclaim CDW once it is deposited at landfills. As this study has found, this approach is already in practice at a landfill in the Limpopo Province, where reclaimers generate income for their subsistence. While this approach to CDW management encourages landfilling, it also ensures that operational costs for construction companies are significantly reduced. Literature in this study has revealed that running heavy-duty industrial CDW recycling technologies requires significant capital investment, which many construction companies in South Africa cannot afford. Deployment of informal waste reclaimers could cut costs for construction companies while creating employment and promoting the circular economy in construction.

The integration of informal waste reclaimers discussed above could potentially help to significantly reduce 'waste' and match the concept of green construction. Yet, the proposed approach on its own is still permeated by a considerable limitation where significant volumes of cementitious mortar and other small construction debris cannot be reclaimed this way. Through the adoption of industrial ecology, the current characterization of cementitious mortar and other small construction debris as unsalvageable materials can be mitigated. Through the deployment of low-cost industrial granulators and crushers at South African landfills, cementitious mortar and other small construction debris can be further processed into fine aggregates that can be galvanized with plastic waste from other industries to make eco-paving material used in civil engineering. Therefore, rather than deploying paving material manufactured from virgin material, an industrial ecology approach can be deployed to reduce both the cost of construction and pressure on the environment.

# CHAPTER FOUR

# EMPIRICAL EVIDENCE

## Overview of the chapter

This chapter is composed of two papers. One has been published and another is currently undergoing peer review in accredited journals, and they form part of the empirical evidence of this study. The significance of this chapter is that it provides empirical data on the environmental performance of construction and demolition waste (CDW), specifically on wetland ecosystems in the Gauteng Province of South Africa. This chapter responds to the 'Studies Question no. 2' and 'Objectives II and III' outlined in Chapter 1. Studies by Fitchett (2017) and Mangoro & Kubanza (2023) argues that growth in urbanization has increased the frequency of illegal dumping of waste e.g. CDW, into aquatic ecosystems such as wetlands in the low-income areas of the Gauteng Province. It is argued that the practice of dumping CDW in wetlands has significant environmental ramifications, although existing studies only peripherally refer to this matter. Academic studies on the environmental performance of CDW in South Africa remain largely scarce or non-existent, and the purpose of the papers forming this chapter is to reduce this knowledge gap, and the value of these papers is immediately apparent.

The first paper investigates the effects of CDW on wetland ecosystems in Gauteng, South Africa. This investigation was informed by semi-structured interviews with experts from environmental epistemic communities in the City of Johannesburg. The paper also studied the effects of CDW disposal in wetlands using GIS and Remote Sensing tools, where elevation changes due to dumping were investigated and mapped for analysis. Several studies investigate the environmental performance of waste through the lens of toxicity. These studies are informed by the fact the environmental impact of waste materials can no longer be viewed in the lens of toxicity alone, but also through the inherent physicality. It is argued that the approach to pollution or environmental risk through the lens of toxicity is conceptually limited and does not consider that pollution can occur through the physicality of waste materials.

This paper argues that, despite the general lack of active chemicals embedded in much of CDW, its effects on the environment, especially wetlands, can be through its inherent physicality and ubiquity which can cause massive sedimentation and disrupt the ability of wetlands to provide habitat, sequester carbon, filter water, and attenuate floods among other functions. It is ultimately concluded there is a need for legislation, policies and applicable norms and standards to enable implementation and/ or enforcement to hold stakeholders accountable. It also argued that there is a need for more investment in recycling technologies to reduce the reliability of landfills or the environment for virgin construction materials. It is also recommended that a multi-stakeholder management programme should be formulated for waste management and to enhance environmental sustainability. Lastly, as previously argued in the preceding chapters, there is a need for the formation of an online based platform for CDW management, where data sharing is the central tenet.

The second study deploys remote sensing datasets to investigate and quantify land use and land cover changes in Diepsloot and Tembisa from the year 2000 to 2020, to predict the state of wetlands by 2040. The contribution of this paper to this study is to demonstrate that construction and CDW can cause massive damage to the environment (specifically wetlands) outside of the concept of toxicity which generally informs waste classification in South Africa. The results of this investigation suggest that if the levels of dumping in the last twenty years (2000 to 2020) continue the same trajectory, wetlands in the study area will almost completely disappear by year 2040. It is argued that construction and CDW pose significant risks to the existence of wetlands or their ability to provide ecosystem services which include among others, flood attenuation, carbon sequestration, water filtration, and water recharge to rivers. For humanity, this has far-reaching consequences, because construction and the related waste disrupts services such as provision of food, water, and cultural functions among others (see Mandishona & Knight, 2022). It is concluded that a study of this nature is crucial in a water-scarce country like South Africa because it provides a basis for proactive management and decision-making.

## Paper No 3.

## Assessing the Effects of Construction and Demolition Waste on Wetland Functionality in Gauteng, South Africa[4].


### Abstract

The global construction sector has grown significantly in recent decades due to rapid urbanization and population growth. The growth of the sector spells many positive possibilities for humanity and the world economy in terms of trade, employment, profits, and global cohesion, among other things. However, the construction sector poses serious threats to the environment particularly through materials extraction, rapid waste generation, and poor handling practices building materials. This paper assesses the effects of construction and demolition waste on wetland ecosystems in the context of the Gauteng Province of South Africa. It uses a mixed-method studies approach of semi-structured interviews, and remote sensing methods to investigate the effects of construction and demolition waste in the context of Diepsloot and Tembisa, located in the City of Johannesburg and the City of Ekurhuleni Municipalities. It is argued that CDW is a massive anthropogenic pollutant that affects wetlands through its physicality and mineralogical profile. The study finds that CDW causes disruption of water discharge, water pollution, species and habitat loss, and flooding, and contributes massively to the undesired global trend of wetland deterioration and disappearance. With these findings, it is concluded that CDW management in developing countries requires urgent transformation, particularly regarding policy, law enforcement, and changes in attitude towards waste by the construction sector, among other things.



**Keywords**: Construction and demolition waste, wetlands, deposition, remote sensing, environment.


[4] This paper is under consideration in the Global Environmental Change Journal: Mangoro, N., Kubanza, N.S. & Simatele, M.D. (2024). Assessing the Effects of Construction and Demolition Waste on Wetland Functionality in Gauteng, South Africa.

## 4.1. Introduction

The construction sector is one of the largest and most rapidly expanding sectors of the global economy in the 21st century (Govindan et al., 2016; Mehran, 2016; Gurney et al., 2021). The expansion of the sector is evident through rapid urbanisation across the world, which demands new construction or expansion of existing infrastructure (Ahmad et al., 2019; Zhang et al., 2021). Recent studies forecast that the construction sector will expand to a global output of approximately US$13.3 trillion by 2025 and US$15.2 trillion per annum by the year 2030 (Gurney et al., 2021). These figures suggest a high level of global commitment to the development of economic and social infrastructures. Based on the current global construction trends, some observers have already drawn attention to the possibility that the construction sector will soon become the mainstay of the global economy (Turner & Townsend, 2018; Gurney et al., 2021). The realization of this prediction spells many positive possibilities for humanity and the world economy in terms of trade, employment, profits, and global cohesion, among other things.

However, the problem with the growth of the construction sector is that it poses serious threats to the environment. For example, associated problems of water, soil, and atmospheric pollution by construction and demolition waste (CDW) have been reported in many parts of the world (e.g. Fitchett, 2017; Mohammed and Elias, 2017; Kaluarachchi et al., 2021; Mehra et al., 2022; Rangecroft et al., 2023), and this is partly because of the consumptive and wasteful nature of the industry (Guerra et al., 2021). Studies suggest that the construction industry consumes approximately 3 billion tonnes of natural resources per year in the global economy (Guerra et al., 2021; Mehra et al., 2022). This figure points to a rapid expansion of the construction sector to meet the rising needs of human processes. However, this figure appears to be very conservative considering a study by the United Nations (UN) several years prior. In this study, it was established that the world construction sector utilizes approximately 40 to 50 billion tonnes of sand and aggregates per annum, with a substantial projection of up to 60 billion tonnes by 2030 (UNEP, 2019). Such a huge disparity in the quantities of construction materials suggests a lack of rigorous and accurate quantitative methods to measure the combined total of raw materials in the global construction sector. Despite the lack of consensus among scholars, the intrusion by humanity into the natural environment for raw construction materials is an environmentally disruptive process because it involves massive earthworks, rock harvesting, and forest clearance, which impedes the ability of nature to perform its functions (see Steinfeld & Kingsford, 2013; Mathodi et al., 2020; Luo et al., 2021; Bogoviku & Waldmann, 2021). The biggest environmental concern, however, emerges from the fact that the construction sector alone generates approximately one-third of the global waste output from economic activities, and about 40% of the global carbon dioxide emissions (Papargyropoulou et al., 2011; Miller, 2021). A high output of carbon dioxide emissions contributes significantly to global warming and general ecological imbalances that characterize the Anthropocene epoch.

In response to the rising environment-related problems from CDW, policies have emerged in the last decade, which demonstrate a strong commitment to mitigating emergent issues, particularly in developed countries. An example is that the European Union (EU) promulgated the 'EU Waste Framework Directive 2008/98/EC' to encourage transition to the circular economy in construction and other industries (European Commission, 2008). By design, the concept of circularity encourages the reduction, recycling, or reuse of materials to eliminate or reduce waste, and limit the extraction of virgin materials from the environment (Kirchherr et al., 2017). Ultimately, players in the European Union construction sector have responded massively to policy demands, recycling over 70% of CDW by 2020 (see Castell-Rüdenhausen et al., 2020). The expansion of the recycling economy suggests a reduction of illicit waste economies in the European Union through elimination of unwanted materials. However, investigators observed that the European construction sector was sceptical of the quality of recycled aggregates, resulting in the accumulation of circularized materials across the continent (Park & Tucker, 2016; Katerusha, 2021). To mitigate this problem, the European Union additionally promulgated the 'EU Construction and Demolition Waste Management Protocol', which aims to increase confidence in the quality of recycled aggregates (European Commission, 2018), while debates continue to emerge about the formulation of the best strategies to sustainably conduct construction. The reactive promulgation of policy to address the CDW management-related problems (through policy) indicates a strong, coordinated, and collaborative stance to eradicate or minimize the negative environmental effects of construction materials.

In contrast to the European Union's approach to CDW management's environmental challenges, governments in developing countries, especially those in sub-Saharan Africa (SSA) lack financing or investments. Several studies in the SSA region corroborate this view, and the key argument presented by investigators is that the region lacks robust waste management frameworks and potent governance systems (e.g. Nyika et al., 2019; Godfrey et al., 2019; Mangoro & Kubanza, 2023). An example is drawn from the South African Waste Act (No. 59 of 2008), where CDW is regarded as 'general waste' that does not require special treatment. The problem with this classification is that it bars opportunities for allocation of special funding for treatment or general management of the waste stream. Furthermore, waste studies in SSA hold the consensus that weak policy motivates massive illegal dumping, particularly in secluded or isolated environments (e.g. Fitchett, 2017, Godfrey et al., 2019; Mangoro & Kubanza, 2023).

Considering the above, it is apparent that CDW poses massive threats to the environment especially in the absence of collaborative and well-coordinated waste management approaches. Yet, in the SSA context, scholarly attention to CDW management environmental problems is very limited, particularly on how the waste stream affects riverine ecosystems such as wetlands. This is a major study gap, because wetlands are fast disappearing in SSA despite their ecological contribution, due to massive illegal dumping or other human activities such as agriculture (e.g. Mandishona & Knight, 2022). Wetland ecosystems play an essential role in earth processes such as flood attenuation, providing habitat and water to various species, and reducing atmospheric carbon dioxide among other roles (Ehrenfeld, 2000; Lolu et al., 2018; Rangecroft et al., 2021). Based on this, a lack of studies on how wetlands are affected by human processes requires urgent scholarly attention. Using the Gauteng Province of South Africa as a case study, this article assesses the effects of the deposition of CDW on wetland ecosystems using qualitative surveys and spatial information technologies. With this goal in mind, the major objective of this study is to provide critical perspectives for sustainable management of CDW in South Africa and to propose strategies for sustainable management of wetlands in urbanizing contexts. Since no previous study has investigated this problem in the region, the findings of this investigation can be used as a template for CDW management and wetland conservation in SSA, and the value of the study is immediately apparent.

### 4.2. A synthesis of the literature on the environmental performance of CDW in developed and developing countries.

Studies on CDW in both developed and developing countries explain that it is a highly heterogeneous, ubiquitous, and voluminous waste stream (Aboginije et al., 2020). This is because construction processes involve many distinctive materials with different chemical and physical properties such as cement, gypsum, glass, plastic, soil, wood, and metal, which affect the environment in distinctive ways (Muigai et al., 2013; Aboginije et al., 2020). This nature of CDW presents urban managers in developed and developing countries with major administrative challenges, and this typically manifests through illegal dumping on a massive scale (e.g. Fitchett, 2017; Elshaboury & Marzouk, 2019). Such a problem arises from the fact that heterogeneous CDW requires massive capital investment for separation, treatment, or transportation and disposal (Ferronato & Torretta, 2019). In the absence of strong and coherent waste management systems such as in developing countries, the environment bears the brunt through illegal dumping and disposal without pre-treatment (Elshaboury & Marzouk, 2020). Despite being a global scale nuisance, CDW presents stronger environmental and administrative problems in developing countries more than in developing countries, because much of the solid waste management concepts and technologies emanate from the global north. The problem with this model of waste governance is that developed and developing countries have strong technological and financial disparities, with the latter being very poor.

Most studies on CDW advance the idea that the waste stream can cause environmental degradation on a massive scale. A synthesis of the literature on this subject suggests that CDW can affect the environment in its four temporalities of water, air, land, and subterranean localities, making it a potent source of pollution (Kaluarachchi et al., 2022; US-Environmental Protection Agency, 2022; Mehra et al., 2022). To illustrate these problems, scholars have in the past two decades consistently shown that CDW can cause massive atmospheric pollution through fine dust dispersion from demolition sites (Kaluarachchi et al., 2022; US-Environmental Protection Agency, 2022; Earth5R, 2023). Examples of this can be drawn from case studies in the United States of America, Sri Lanka, India, and South Africa (see Kaluarachchi et al., 2022; US-Environmental Protection Agency, 2022; Earth5R, 2023). Drawing from the United States, CDW dust is reported to have contributed to regional haze formation, nutrient loading algal blooms in marine environments, and plant deaths in New Hampshire (New Hampshire Department of Environmental Services, 2018). Similarly, an investigator working in an Indian case study observed that construction dust comprised 38% of particulate matter dust with a diameter of less than 10mm in the atmosphere in Delhi, and 70% of atmospheric pollutants in Mumbai, rendering the Indian atmosphere highly polluted (Earth5R, 2023). Similar questions have been raised in South Africa, and it was observed that CDW dust from road construction sites causes the deterioration of vegetation (Al Festus, 2019). These findings support the notion that CDW is a massive environmental pollutant that requires urgent attention.

Other investigators examined the environmental effects of fugitive CDW dust on a planetary scale perspective. These investigators observed that atmospheric CDW dust dispersion generally affects the radiative capacity of the earth, alters rainfall trends, or disrupts biogeochemical cycles, to cause among other things, a greenhouse effect and global warming (Rohracher, 2001; Darkwah et al., 2018). This is a radical scientific discovery because the greenhouse effect and global warming can cause long-term disruption of Earth's systems long after contemporary generations. But what precisely does the greenhouse effect do? Studies has established that the greenhouse effect traps solar radiation in the earth's atmosphere and traps excessive atmospheric heat which makes the planet unfit for earth's life and systems (Khan, 2017). From this perspective, it can be argued that atmospheric pollution from CDW dust can have severe environmental effects with the ability to affect earth's life and systems long after current generations.

On the other hand, the environmental effects of construction and its waste (CDW) cannot only be viewed in the perspective of atmospheric pollution, and to illustrate this, we draw upon empirical studies across the globe. Surveys, such as those conducted by Muigai et al. (2013), show that even the extraction process of construction materials from the environment, and their subsequent handling to produce final building products, can have negative effects on the environment. According to Muigai et al.'s (2013) survey, roughly 39.7Mt of raw materials were extracted from nature in South Africa between 2005 and 2008 to produce concrete alone, and the procedure generated 4.92 x $10^9$ kg of carbon-dioxide equivalent (CO2-e). These outcomes support prior findings of the Energy Report (2010), that the manufacturing of building aggregates produces an average of 8.1kg of $CO_2$ equivalent in South Africa. Such pollution is primarily caused by the breakdown of limestone ($CaCO_3$) to calcium oxide (CaO) and the combustion of coal for the energy required in the manufacturing process (Association of Cementitious Material Producers, 2011). To further support these empirical findings, studies in the Global North suggests that the construction sector in the United Kingdom consumes approximately 170 million tonnes of materials for construction per year (Mehra et al., 2022). A greater fraction of this material (125 million tonnes) comprises quarry products, where approximately 6 million tonnes of energy is consumed in the manufacturing process, whereas 23 million tonnes of carbon dioxide disperses into the atmosphere during the same process (Mehra et al., 2022). What these findings suggest is that the extraction and handling processes of construction materials has a significant global warming potential.

While investigating atmospheric pollution from construction projects is a continuing concern within the field of environmental studies, other observers have drawn attention to the disruptive tendencies of CDW in marine environments. Studies in Germany, Canada, South Africa, Sri Lanka, and Ethiopia demonstrate that sediments from construction sites often migrate to rivers through water and wind erosion, and ultimately cause water pollution and disruption of river drainage and discharge (SA-DEA, 1998; Ministry of Environment-British Colombia, 1999; Fitchett, 2017). This is supported by an empirically grounded study on the subject, which concluded that wetland pollution with CDW has far-reaching ramifications for riverine biomes. In this study, scholars argue that bodily encounters with CDW by aquatic species cause ingestion and migration of toxic trace elements into biological systems, and cause significant harm known through bioaccumulation. This view emerges from Staunton et al.'s (2014) study, which discovered that Deroceras reticulatum (a type of slug) from wetlands infilled with CDW in Ireland were significantly contaminated by elements such as copper, thallium, antimony, arsenic, and barium among others, which biologically accumulated over extended periods. The significance of these findings was confirmed in an experimental study in Bangladesh, which revealed that just two weeks of exposure of fish to water contaminated with arsenic causes noticeable 'morphological abnormalities and deformities…' (Rabbane et al., 2022). Conclusions from these empirical studies challenge the widely held view that CDW is inert or chemically inactive and therefore causes no harm to the environment.

It is imperative to note that the issue of water pollution from CDW continues to grow in significance, especially in view of recent findings by Tau et al. (2021). In this study, it is observed that 30% of construction wastewater is discarded into the environment in developed countries without treatment, whereas in developing countries, the figure exponentially rises to 90% (Tau et al., 2021). These results are noteworthy because they corroborate conclusions from earlier studies noting that construction generates high volumes of toxic sediment and silt (e.g. SA Department of Environmental Affairs, 1998; Elias, 2017). An investigation into the Ethiopian Rivers of Akaki, Kebena, and Bulbula showed that waste migrating from construction sites contributed to massive pollution going beyond permissible levels (Elias, 2017). These findings emphasize that CDW has increasingly become an urban environmental challenge in cases where management lacks rigour.

Although the above issues are of major environmental concern, it is important to note that CDW causes other types of massive disruption of marine and freshwater systems. Several studies have found that CDW can reduce sunlight penetration into marine and freshwater ecosystems (SA Department of Environmental Affairs, 1998; Elias, 2017; Gardner et al., 2019). Drawing on a study by Gardner et al. (2019), the presence of CDW materials in marine ecosystems reduces sunlight penetration into river currents and reduces the rate of decomposition of organic matter. From a viewpoint of marine life, a shortage of sunlight negatively affects the development of algae and other marine plants which provide food for various marine organisms (e.g. Dountchev et al., 2017). Accompanying this problem is the fact that CDW pollution affects river drainage, causes artificial floods, and disrupts migration patterns of marine organisms (Dountchev et al., 2017; Jikeka et al., 2019). Based on these findings, it can be argued that water pollution from CDW can have significant effects that go beyond human systems.

Other global data-based studies have shifted attention to cases of soil pollution from CDW. Scholars focusing on this problem communicate that toxic CDW substances including oils and cementitious materials can contaminate the soil with various materials including 'forever chemicals' (see Muigai et al., 2013; Agbede et al., 2022; Chamberlain et al., 2022). 'Forever' contaminants cause major environmental anxieties to researchers and policymakers because they last beyond human time and exist in geological timeframes, while their remediation only shifts materials in space rather than permanently destroying them (Liboiron, 2016; Gray-Cosgrove et al., 2015). To support this argument, reference can be made to an Australian study by Chamberlain et al. (2022), who espouse that CDW can contaminate the soil with per- and polyfluorinated alkyl substances which can last forever in the affected landscape.

Other scholars argue that per- and polyfluorinated alkyl substances are crucial in construction because they 'repel water, dirt, and grease…' which makes it difficult to eliminate them from building processes (Buck et al., 2011). On further analysis, these substances are crucial in construction but when deposited in soils, they prevent water percolation and subterranean gaseous exchange because of the embedded waterproof nature. Debnathi et al. (2019) and Hwang & Yeo (2011) support these findings, arguing that CDW drastically contaminates the soil by increasing its acidity or alkalinity, biochemical oxygen demand (BOD), and total dissolved solids (TDS). Based on these investigations, land contamination from CDW is calamitous to the environment because healthy soils are essential for environmental systems and maintenance of equilibrium.

Additionally, the deposition of CDW onto certain types of soils has special negative effects on groundwater quality. Dissolved CDW waste minerals such as arsenic, chromium, petroleum, and copper concentrations can pollute groundwater through the process of infiltration (see Emmanuel et al, 2014; Galitskova, 2019). A scientific analysis of the effects of CDW on light grain soils in the Samara Region of Russia indicated that pollutants such as petroleum products used in construction can exist in the soil for long periods, and gradually release them into groundwater (Galitskova, 2019). This is environmentally hazardous in the affected area, and in the broader context of groundwater conservation, infiltration of CDW toxins is a big problem, especially because construction uses about 15% of the earth's freshwater (see Othman, 2009). Considering that only 3% of earth's water is scientifically considered fresh, the problem of CDW pollution requires urgent attention.

The environmental concerns discussed so far tend to be focused on the mineralogical compositions of CDW and how they disrupt environmental systems. However, it is important to note that the effects of CDW on the environment cannot be viewed only through the lens of their chemical profiles and their ability to pollute. In this perspective, a considerable number of scholars agree that CDW is a concern for the environment, because it rapidly consumes space which can be profitably utilized for other purposes in developed and developing countries (see Macozoma, 2006; Aboginije et al., 2020). Given that many developing countries largely depend on landfilling as a way of managing CDW, the use of landfills poses high risks to the environment, especially because in some regions like Asia, it takes up over 50% of available space (Hwang & Yeo, 2011). While many scholars stress the argument of rapid land cover of CDW, existing studies have completely overlooked the fact that landfilling simply congregates waste from various construction sites and causes more potent environmental problems. Arguing in the context of pesticides, Balayannis (2018) concluded that the removal of synthetic chemicals from places of storage to disposal locations simply entails removal from public view, but the pollution remains. Similar arguments can be deployed in the case of CDW management through landfill disposal because local governments in SSA are more concerned with removal and disposal in permitted sites. Disposal in landfills, however, only intensifies cycles of soil, air, and water pollution.

Even though the literature reviewed in this study provides considerable knowledge about the environmental performance of CDW, limited studies have been done in SSA countries like South Africa to examine its effects on wetlands. Wetlands are the most targeted environments for dumping CDW in South Africa, despite their significance in earth processes. Such a gap in literature attracts studies' attention, particularly in the context of the increasingly devastating effects of climate change. The era of climate change requires a multifaceted approach to the effects of anthropogenic pollution. In a period of increased significance of adherence to life within planetary boundaries, wetlands have become increasingly important and therefore are worth conserving. Studies have established that wetlands provide humanity with protein, water, and fertile ground for agricultural purposes (e.g. Mandishona & Knight, 2022). Other scholars posit that wetlands provide habitat and food to marine organisms, perform water filtration, minimize flood risks, and act as carbon sinks among other things (Ehrenfeld, 2000; Lolu et al., 2020; Mandishona & Knight, 2022; Rangecroft et al., 2023). Therefore, it can be argued that wetlands are of multi-layered significance to earth systems, and given this background, this study assesses the effects of CDW on wetland ecosystems, using the Gauteng province of South Africa as a case study. Studies of this nature provide the much-needed awareness of the effects of CDW dumping on these important ecosystems, and the possible solutions.

## 4.3. Materials and methods

### *4.3.1. Study area*

This study is based on a multi-sited ethnography in Diepsloot (25.9396°S, 28.0128°E) and Tembisa (26.0093°S, 28.2181°E) in the Gauteng Province of South Africa. The two case studies fall under the City of Johannesburg Municipality and the City of Ekurhuleni Municipality respectively (Figure 1.1). The study areas adopted an apartheid settlement style, which sought to segregate Black from White communities during the colonial period (Benit-Gbaffou, 2002; Benit-Gbaffou et al., 2013). The settlements are characterized by both formal and informal settlements, which mushroomed particularly in the last 20 years.

The two settlements are situated in a catchment area formed by permanent water bodies such as the Jukskei, Diepsloot, and Kaalspruit Rivers, and their tributaries. This hydrological system is also typified by heavily polluted wetlands (Figure 4.1), with seasonal flooding in the recent decade (Fitchett, 2017; Mangoro & Kubanza, 2023). In some areas, the wetlands constitute a habitat for the near-threatened African Giant Bullfrog (*Pyxicephalus adspersus*) species (Yetman & Ferguson, 2011; Mangoro & Kubanza, 2023), whereas the riparian zones are home to the Grass owl (*Tyto capensis*), making the study region an ecologically sensitive region (Envirolution Consulting, 2018). In terms of geology, the study area falls within the Savana Egoli Granite Grassland, with moderately sloping terrain and low hills, which is crucial for river drainage and erosion. Additionally, the associated vegetation is the tall *Hyparrhenia hirta* (Mucina & Rutherford, 2006), making the study area a highly heterogeneous environment. The climate is typified by dry winters and an annual average rainfall of 680mm (Mucina & Rutherford, 2006).

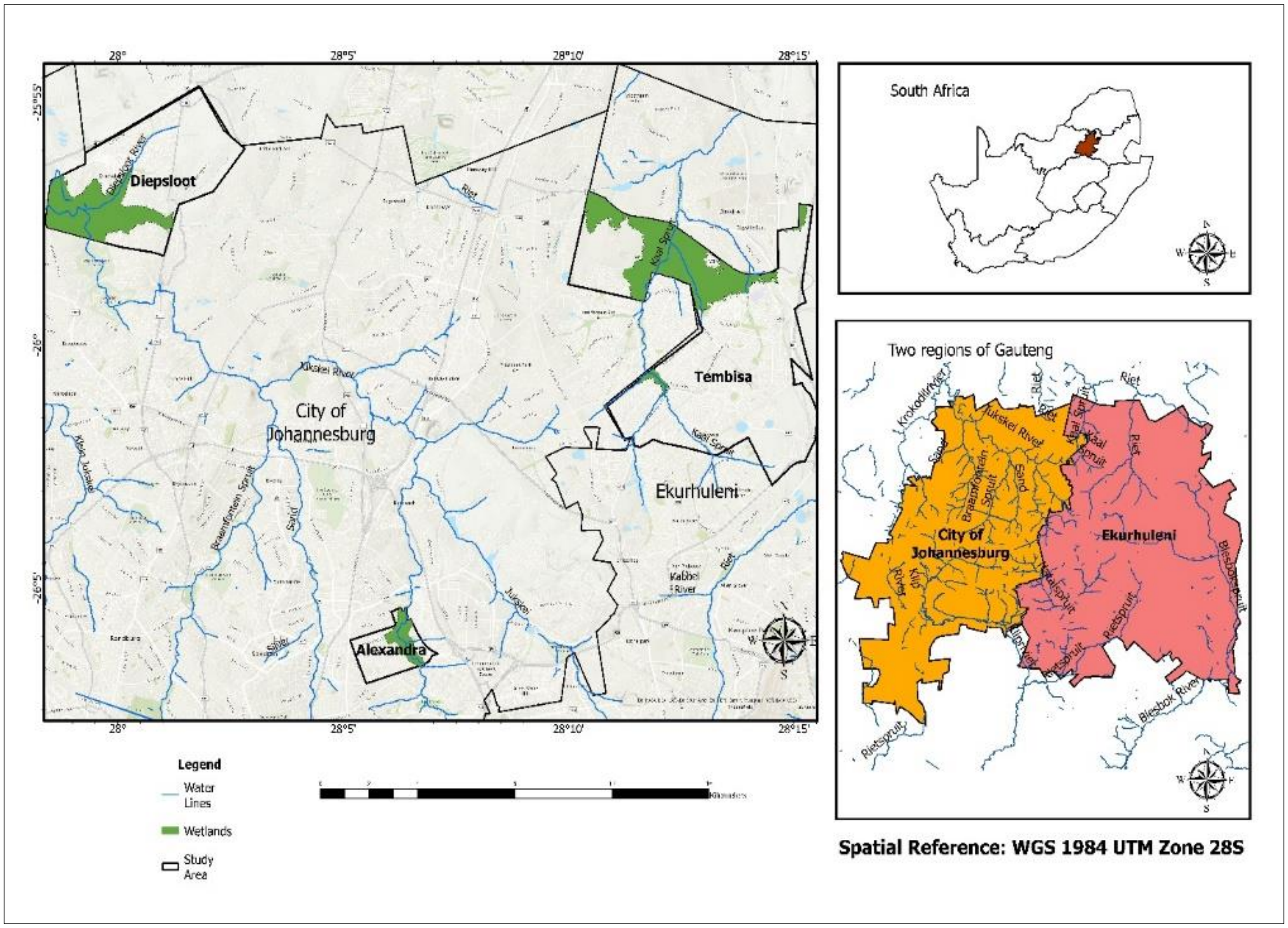


**Figure 4.1 Location of the study area and the associated hydrological systems in the Gauteng Province.**

*Source of Map: Researcher, 2023.*

### 4.3.2. Data collection and analysis

This article is informed by both primary and secondary data sources. The primary data was collected between October 2022 and June 2023 in the Gauteng Province of South Africa (Diepsloot & Tembisa). To acquire primary data, the study deployed a multi-sited ethnography based on participatory action studies. Semi-structured questionnaires and virtual interviews were deployed to explore the perspectives of study participants on the effects of CDW dumping on wetland ecosystems in the study areas. Study participants were recruited through a purposive sampling strategy from four epistemic communities. Once the sampling strategy was decided, participants were drawn from 20 environmental non-governmental organizations (e-NGOs) in Johannesburg. Participants were also recruited from the Johannesburg Metropolitan Municipality (JMM), the Provincial Government Department called 'Gauteng Department of Agriculture and Rural Development' GDARD, and the Department of Forestry, Fisheries and the Environment (DFFE).

The purposive sampling strategy deployed in participant recruitment was based on the principle that each participant had at least 3 years of professional experience in environmental conservation or management. This was a crucial principle because the participants were required to have reasonable professional experience to produce adequately informed perspectives. However, because either most of the epistemic communities did not have websites, or they lacked detailed organograms where purposive sampling could be deployed to recruit participants with over 3 years of professional experience, snowball sampling was used as a complementary tool to identify participants. Therefore, the participants recruited through purposive sampling were asked to identify potential participants who suited the recruitment criteria. Once the recruitment process was completed, the distribution of participants from each epistemic community were as follows, GDARD (n=3), JMM (n=3), DFFE (n=3), and e-NGOs (n=24).

The interview schedule/questionnaire administered to the participants was largely homogenous in terms of the questions. Generally, the questions were carefully designed to capture perceptions on how CDW is managed and how it ended up in wetlands in the study areas. However, a small fraction of questions was 'community' specific since each class of organisation would have specialized portfolios distinctive from those of the others. The decision to deploy questionnaires and virtual interviews was considered suitable for the study because the experts were not easily accessible due to busy work schedules in the period of economic recovery in the aftermath of the Covid-19 pandemic. Finally, the data were processed and analysed using thematic analysis, which identifies codes and themes from the collected qualitative data (Braun & Clarke, 2019).

In addition to the primary data, this study was informed by existing literature on the effects of CDW on the environment, focusing on the context of both developed and developing countries, since the effects of CDW on the environment are universal. The process of searching for literature was conducted between December 2022 and May 2023. Literature was drawn from a rigorous search in library databases from the following universities: the University of the Witwatersrand, the University of Johannesburg, the University of Pretoria, the University of the Western Cape, and the University of KwaZulu-Natal. In addition, other study articles were drawn from internet-based data engines such as Google Scholar, Bing, Yahoo, Web of Science, Scopus, and Science Direct. The literature was searched using the keywords such as 'environmental performance of CDW', 'effects of dumping CDW on the environment' and 'environmental effects of construction'. This process produced 98 articles which were appraised to determine articles suitable for use in the study. The appraisal was based on the 4 major variables including date of publication, study outcomes, location of study, and strictness of peer reviewed studies. The peer reviewed articles were required to be published between year 2000 and 2023 because this is the period of fast urban sprawl in South Africa (Mangoro et al., 2024). In terms of the study outcomes, the articles were required to be data-driven and clearly state the outcome of the analysis. In addition to this, the articles were supposed to be spread over both developed and developing countries in the global north and south to capture the state of CDW environmental impacts across the globe. Finally, all articles were required to be peer reviewed, to inform the studies with high-quality perspectives. Once this appraisal was complete, only 27 articles met the inclusion criteria.

### 4.3.3. Remote sensing

The Digital Elevation Model (DEM) mapping technique was deployed to detect changes in the wetlands in Diepsloot and Tembisa. A DEM is an image representation of the earth's topographic surface which excludes buildings, trees, and other surface objects. It provides a base dataset that can be manipulated to produce topographic elevations of a given location (Wechsler, 2003). Given the capabilities of DEMs in mapping the earth's surface, digital elevation modelling analysis can be performed on riverine environments such as rivers and wetlands and is particularly effective where massive deposition of solid matter is involved. This is because the deposition of solid matter (especially in large volumes) affects the elevation of a given landform. Therefore, it is possible to detect and map areas of erosion and deposition of matter in riverine environments such as wetlands and rivers (Wechsler, 2003).

DEMs were generated on a 10-year interval (2000, 2010 & 2020) to ensure maximum detection and mapping of change in the selected wetlands. Shorter intervals would have provided insufficient opportunity for detectable change, making the objectives of this study difficult to meet. Data manipulation was conducted using several different software. First, the Google Earth Pro application was used to generate klm files for the years 2000, 2010 and 2020 over each study area. The klm files were subsequently imported into a Global Positioning System (GPS) Visualizer application to convert them into the txt file format readable in the ArcMap software. The ArcGIS Pro 3.2.1 software was crucial in the data manipulation process because of its capabilities in processing different types of files. Once the text files were incorporated into the ArcMap software, the files were converted into raster DEM files using the natural neighbour interpolation method (in ArcMap). (The advantage of natural neighbour interpolation is that it handles large numbers of sample points more efficiently). It was then possible to generate a DEM of Difference (DOD) of 2000 to 2010 and 2010 to 2020, using a Raster Calculator in ArcMap. The high values will represent deposition while the lower values will show erosion. To depict a clearer picture, the DOD was reclassified into two classes using the 3D analyst tool in ArcMap (which was done to group certain values together). One group was for deposition and the other for erosion. All the negative values will be in one class, zero to negative (erosion) while the positive values will be in another class, zero to positive (deposition). The results of this process are presented in the following section.

### 4.4. Results and analysis

Depending on location, biota, and geomorphology, wetlands provide distinctive ecosystem services and ecological functions to humanity and nature. As this article is based on the effects of CDW on wetlands, it was necessary to understand their ecological significance. This is crucial because it provides the basis on which to understand the effects of the intrusion of CDW into these ecosystems. As such, a question asking the respondents from e-NGOs to outline the specific functions of wetlands in the study area was posed. Table 4.1 illustrates the results.

**Table 4.1. Perceptions of the ecological significance of wetlands**

| Wetland function | Number of respondents | Percentage Fraction |
|---|---|---|
| Habitat for endangered species (e.g., bullfrogs) | 14 | 42.4% |
| Water purification | 7 | 21.2% |
| Mitigating floods | 7 | 21.2% |
| Water reserve | 5 | 15.1% |
| **Total no of respondents** | **33** | **100%** |

**Source:** Field based material (2022 – 2023).

An analysis of the results in Table 4.1 reveals that all the participants (100%) from environmental e-NGOs understood the context-specific significance of wetlands in the study area. The knowledge can be traced to participants' long-standing experience in environmental conservation in the study area. From Table 4.1, it can be observed that the majority of the participants (42.4%) were of the view that wetlands in the study area provided a habitat for aquatic organisms such as the endangered African Bullfrog (*Pyxicephalus adspersus*), whereas further analysis of the results in Table 4.1 demonstrates that the minority of the participants viewed wetlands in the study area as significant for water purification (21.2%), water reserves (15.1%), and mitigation of floods (21.2%). From these perceptions, it is apparent that wetlands in the study area play an important role in the aquatic ecology of the area.

Since solid waste dumping in wetlands in the study area is not restricted to CDW, it was regarded as important to investigate what varieties of solid waste are involved in environmental crimes in the area. Participants were therefore asked to state the waste streams involved in environmental crimes in the area. The results of this investigation are illustrated in Table 4.2.

**Table 4.2 Participants' Perception of most-dumped waste streams in wetlands**

| Waste Stream | Number of respondents | Percentage fraction |
|---|---|---|
| Construction and demolition waste | 18 | 54.5% |
| Household waste (food, plastics etc.) | 11 | 33.3% |
| Tyres | 2 | 6.0% |
| Mining waste (heavy metals which killed fish). | 1 | 3.03% |
| Garden waste | 1 | 3.03% |
| **Total no of respondents** | **33** | **100%** |

**Source**: Field based materials (2022 – 2023).

The results obtained from the qualitative analysis of data in Table 4.2 suggest that CDW is the largest waste stream illegally dumped in wetlands across the study area. This position is shared by 54.5% of study participants from the environmental NGOs that participated in the study. Despite the dominance of CDW as a waste stream illegally disposed of in wetlands, it is essential to note that household waste (33.3%), tyres (6.0%), mining waste (3.03%) and garden waste (3.03%) also form part of the materials that are deposited in wetlands in the study area. Despite the variability of waste streams listed in Table 4.2, what is noteworthy is the consensus that dumping in wetlands is a huge challenge in the study area. Based on these perceptions alone, it is not an exaggeration to state that wetlands in the study area are highly contaminated by waste materials.

To determine the effects of CDW on wetlands in the study area, participants were asked to state their perceptions on the matter. However, it is important to note that the participants did not perform eco-toxicological analyses of the effects of CDW in wetlands; rather the perceptions were based on visual observations and the long-term professional experience (verifiable using quantitative methods) in environmental conservation in the study area. Figure 4.2 illustrates participant perceptions of the effects of CDW on wetlands in the study area.

**Table 4.3. Effects of CDW dumping on wetlands**

| **Perception** | **No of participants** | **Percentage (%) total** |
|---|---|---|
| Water Pollution | 3 | 9 |
| Habitat loss | 6 | 18 |
| Flooding | 8 | 23 |
| Riparian vegetation loss | 3 | 9 |
| Increase in atmospheric $Co_2$ | 4 | 13 |
| Species loss | 5 | 14 |
| Diversion of river and wetland channels | 5 | 14 |
| **Total** | 34 | **100** |

*Source: Field data (2022 – 2023).*

The data presented in Table 4.3 suggests a consensus among the key participants that CDW can negatively affect wetlands. The drainage of wetlands and the rivers they connect with is essentially dependent on the absence of heavy sediments, which can disrupt their natural functions. From the data presented in Table 4.3, most of the participants alluded to flooding as one of the major effects of CDW dumping in wetland ecosystems in the study area, while 18% stated that habitat loss is also an effect. In addition to this, some experts observed that the frequent disposal of CDW in wetlands also causes the diversion of channels (14%) and loss of species (14%). It is interesting to note that only 9% of the experts alluded to water pollution and riparian vegetation loss as the outcomes of illegal dumping of CDW in wetlands, despite the obviousness of the problem on first sight of the water bodies. One participant with 15 years of professional experience in summed up the effects of CDW on wetlands in the study area.

> *Dumping (of CDW) in wetlands causes loss of natural catchment areas which results in flooding. Also, dumping in wetlands negatively affects plant life in wetlands. The loss of wetlands causes an increase in carbon dioxide emissions and…loss of species.*

The above quotation indicates two important things. Firstly, wetlands in the study area have undergone significant deterioration due to widespread dumping. Additionally, the quotation suggests that the participants were thoroughly aware of the state of wetlands in the study area. What is peculiar about the results in Table 4.3 is that only 9% of the participants believed that CDW causes water pollution, and yet when further asked about the state of water quality in the wetlands, most participants believed that the quality is bad. Table 4.4 illustrates the participant perceptions on this issue.

**Table 4.4: Respondent perceptions on the state of wetland water quality**

| No of respondents | Percentage | Water quality | Explanation |
|---|---|---|---|
| 9 | 27.3% | Poor | Constant contamination by raw sewage |
| 16 | 48.5% | Poor | Constant dumping of CDW |
| 4 | 12.1% | Very Poor | Effluent from unscrupulous industries (e.g. mining) |
| 3 | 9.09% | Unaware | No further explanation |
| 1 | 3.03% | Bad | Lack of community awareness and education on water conservation |

**Source**: Fieldwork material (2022 – 2023).

Based on the data presented in Table 4.4, most of the respondents were aware of the poor state of water quality in wetlands in the study area. Drawing on data in Table 4.4, it is crucial to note that there is a variety of both organic and inorganic pollutants disposed of into wetlands. For example, 27.3% of the research participants were of the view that sewage spillage into wetlands contributed to poor water quality. While wastewater contributes significantly to poor water quality, it is critical to note that CDW is also a contributing pollutant. Data in Table 4.4 demonstrates that 48.5% of the participants regarded CDW as a major pollutant. Considering that CDW is generally considered inert or general waste, this raises questions about how CDW affects wetland water quality.

Perhaps a question that can be posed is whether the CDW pollutes water, or does it disrupt the organic functioning of wetlands? Whatever the case may be, it is worthwhile to note that about 12.1% of the respondents alluded to effluent from mining industries as a contributing factor to 'very poor' water quality. Considering that wetlands across the study area provide habitat to many freshwater species, this raises additional questions about the possibility of species loss stated in Table 4.3. or poisoning of species through bioaccumulation. It must be highlighted that the question of the state of water quality was also posed to four officials from a government department with interests in environmental issues, and interestingly, these experts had a thorough understanding of the state of water quality in wetlands. Lastly, Table 4.4 shows that only 3.03% of the participants thought that water quality in wetlands was bad because of a lack of community education in poor areas. This is likely the case, because communities in the study area are notorious for dumping in riverine environments (e.g. see Mangoro & Kubanza, 2023).

### 4.5. Remote sensing analysis of wetland change

The data presented in this study so far is qualitative in nature, because it is based on perceptions of epistemic communities. This sub-section presents quantitative data which corroborates these perceptions, using DEMs generated over the study area. DEMs were used to observe and quantify the intrusion of solid waste into wetlands in the studies sites. Figure 4.2 and Figure 4.3 illustrates a spatio-temporal analysis of wetlands over the study area from the year 2000 to 2020 on a 10-year interval.

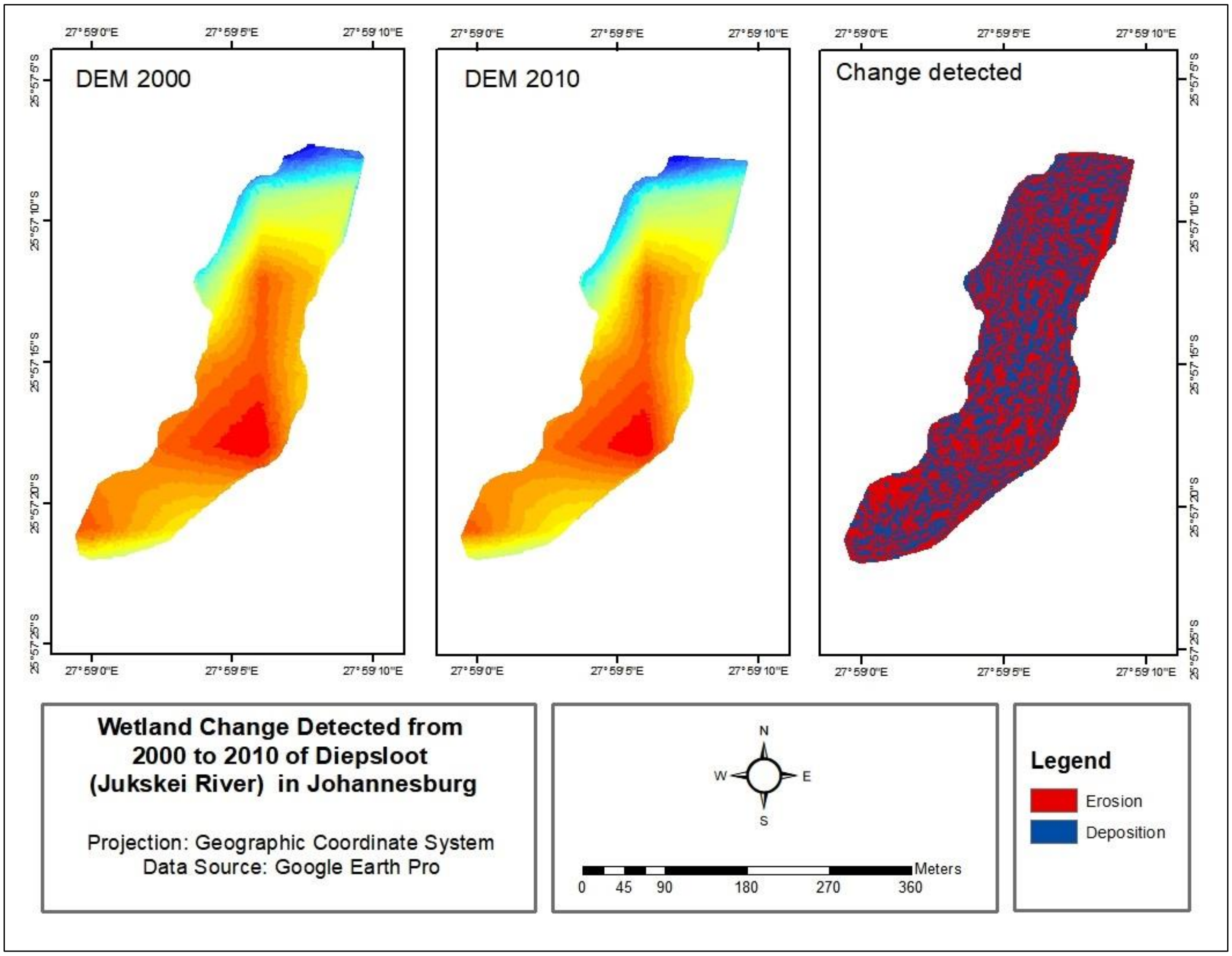


**Figure 4.2: DEM illustrating wetland spatio-temporal change in Diepsloot between 2000 and 2010**

*Source: Author (2023)*

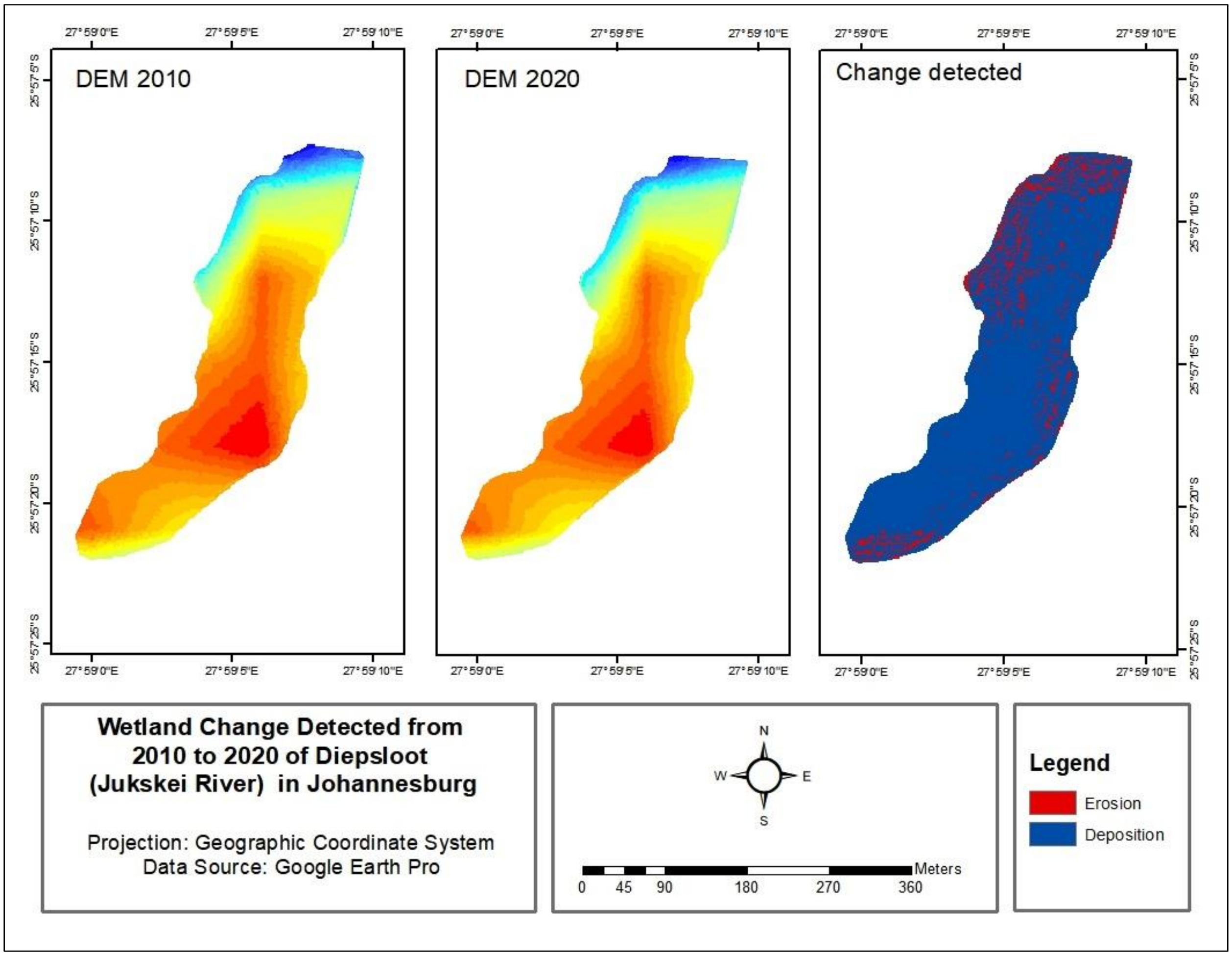


**Figure 4.3: DEM illustrating wetland change in Diepsloot between 2010 and 2020. Source: Author (2023).**

*Source of Map: Researcher (2023)*

Before the year 2000, both study areas did not experience significant urbanization or illegal dumping, and therefore, the wetlands would have been in good condition. In Figure 4.2, which captures spatio-temporal changes between 2000 and 2010 in a wetland in Diepsloot, erosion and deposition of foreign solid matter into the wetland started to emerge. The volume of these changes is illustrated in red and blue on the map, and it should be noted that the wetland was not significantly stressed over this period. A statistical analysis in the ArcGIS software revealed that an estimated 3.68% erosion and 9.02% deposition occurred between 2000 and 2010, which supports the view that little stress was imposed on the wetland.

However, there is a significant rise in the deposition of sediments between 2010 and 2020, and a sharp decline in erosion as shown in Figure 4.3 and 4.4. Further analysis showed that erosion declined to 0.83%, while deposition surged to 21.8% in this period. In river processes, this sharp inverse variation emerges from a loss of water velocity and a decline of slope, which helps generate energy. What is very striking from the rise in deposition is its correlation with population explosion and urban sprawl in Diepsloot, and rapid infrastructural development in the high-income suburbs located very close to the informal settlement, which generate vast quantities of household and CDW. Interestingly, it is also a period where a landfill site in the northern areas of Johannesburg was closed off, resulting in widespread environmental crimes such as dumping.

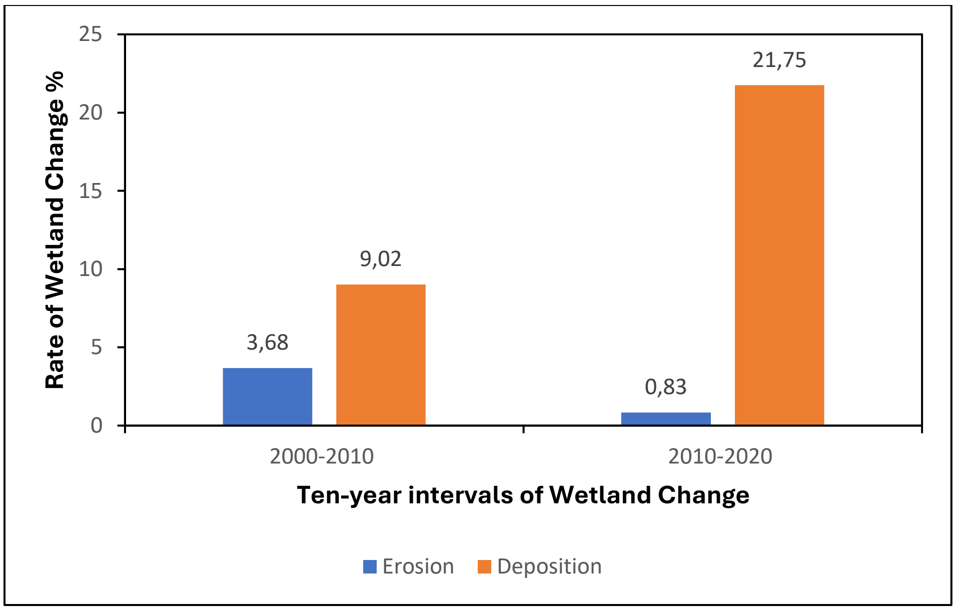


**Figure 4.4: Percentage fluctuations in erosion or deposition in a 20-year period**

*Source: Author (2023).*

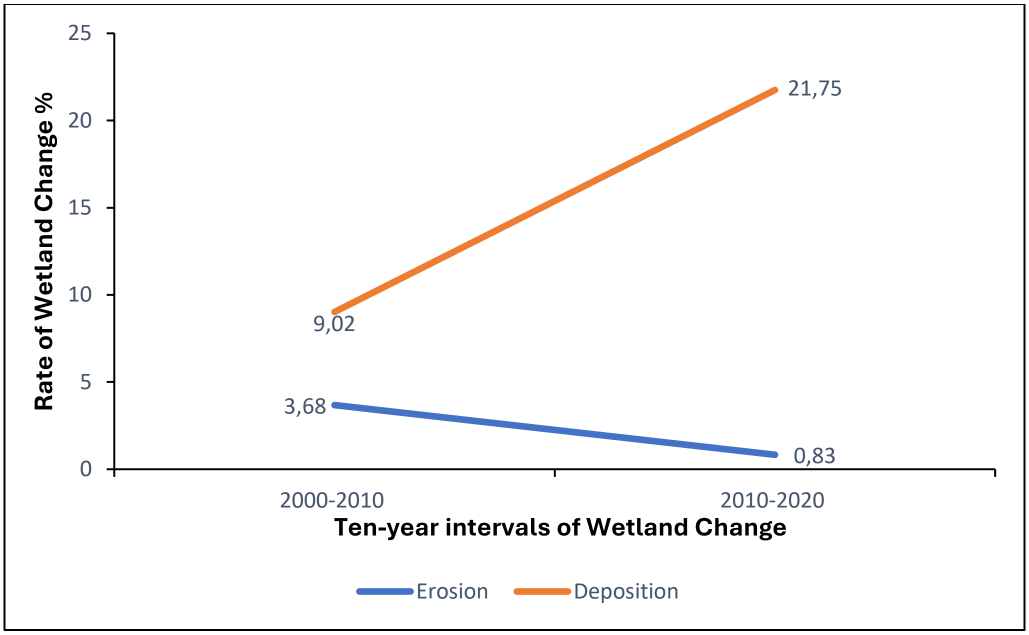


**Figure 4.5: Percentage fluctuations in erosion or deposition in a 20-year period.**

*Source: Author (2023).*

A similar analysis was carried out on a wetland on Kaalspruit River in Tembisa. In Figure 4.6. and Figure 4.7, DEMs shows the spatio-temporal changes in the wetland from 2000 to 2020 over a 10-year interval.

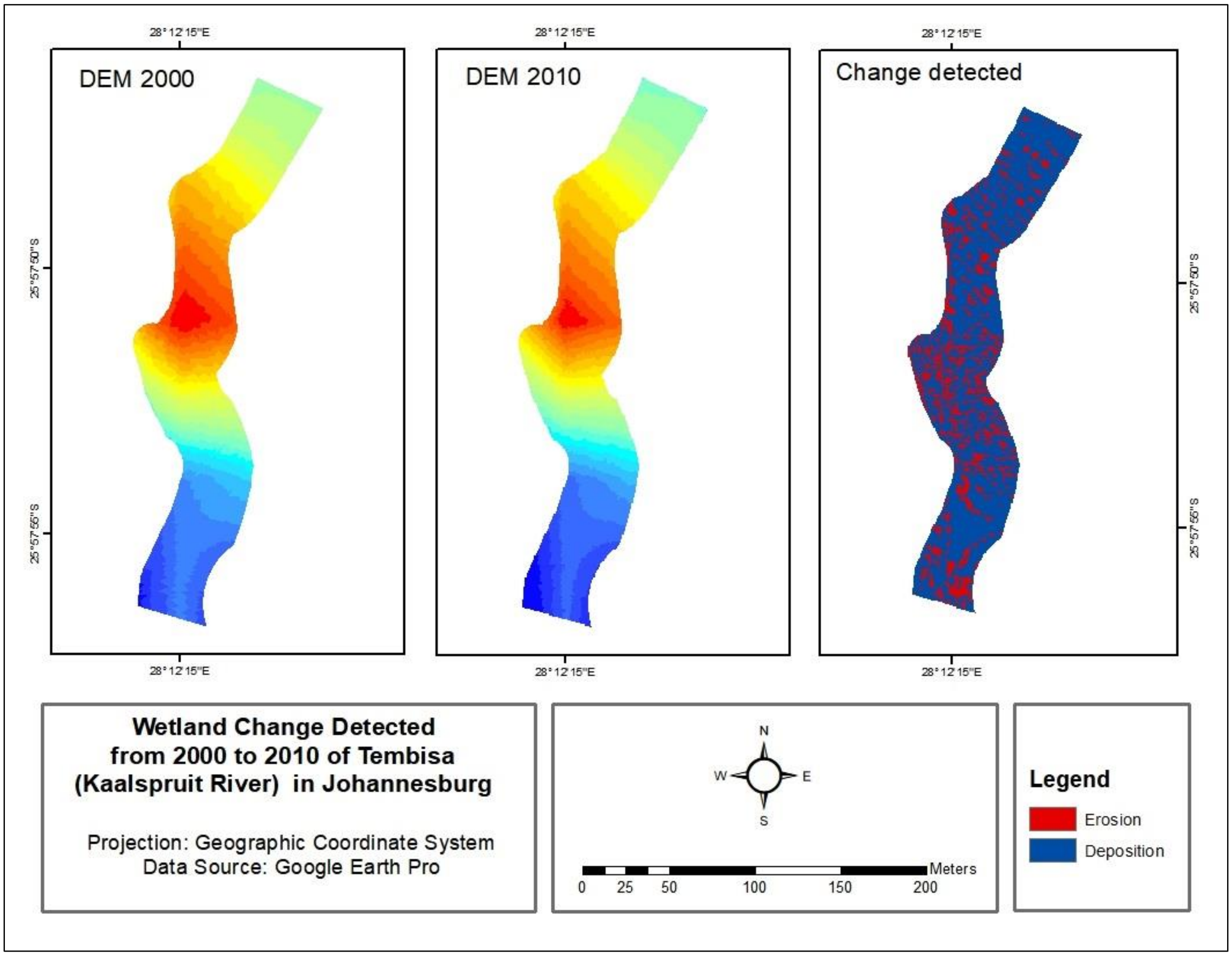


**Figure 4.6: DEM illustrating wetland change in Tembisa between 2000 and 2010.**

*Source of map: Author (2023)*

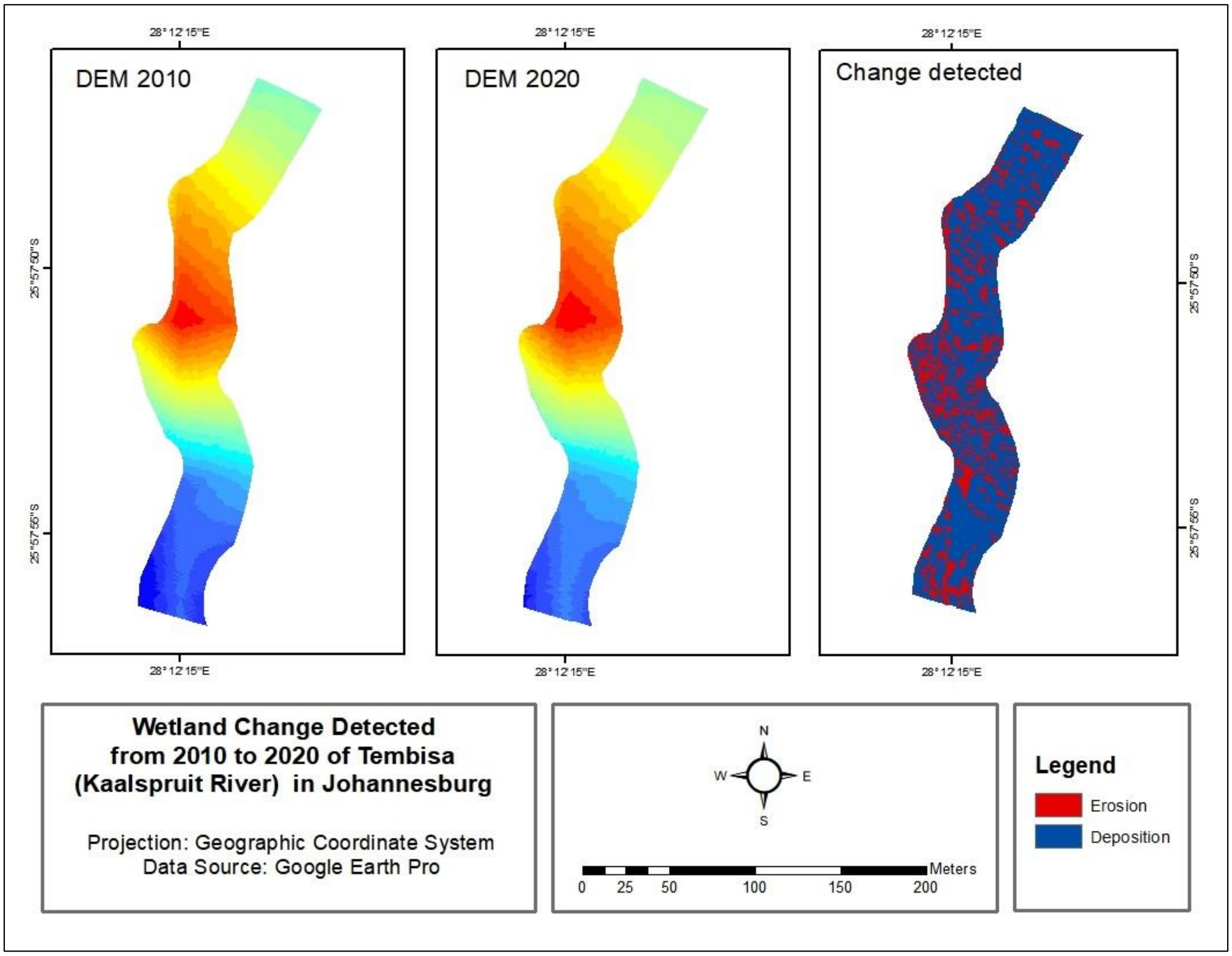


**Figure 4.7: DEM illustrating wetland change in Tembisa between 2010 and 2020.**

*Source of Map: Author (2023)*

In comparison to Diepsloot, a wetland along the Kaalspruit River in Tembisa was also moderately affected by the deposition of solid matter between 2000 and 2010 (Figure 4.6.). A statistical analysis conducted in the ArcMap software revealed that deposition of approximately 6.09% transpired in this period, while erosion was at 2.51%. These statistics suggest that urbanization was slightly higher in Tembisa compared to Diepsloot in the same period. However, between 2010 and 2020, erosion marginally decreased to 2.17% while deposition narrowly rose to 8.92% (Figures 4.8 & 4.9). This suggests that smaller levels of dumping in the wetland took place in this period in comparison to a wetland in Diepsloot.

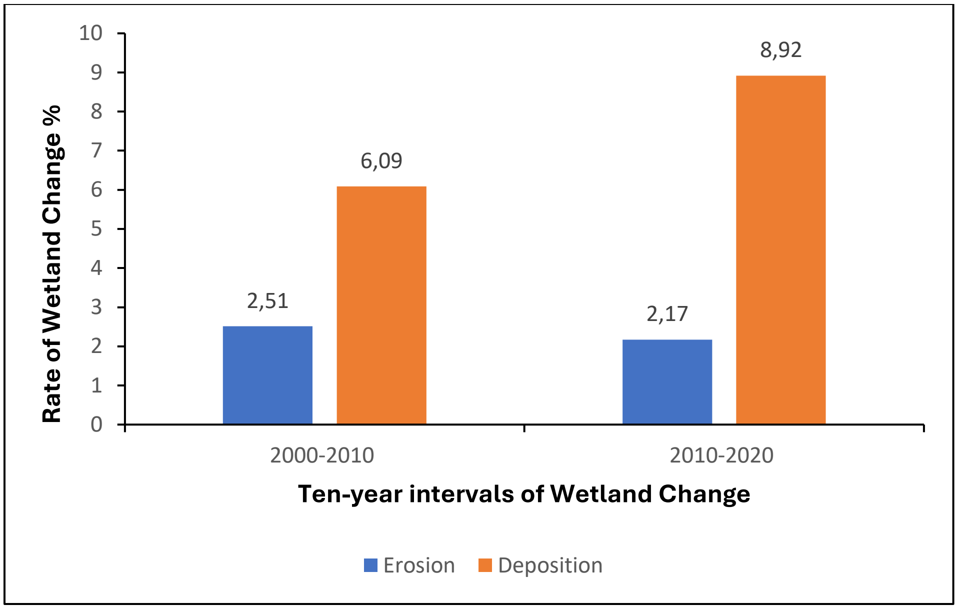


**Figure 4.8: Percentage fluctuations in erosion or deposition in a 20-year period**

*Source: Author (2023)*

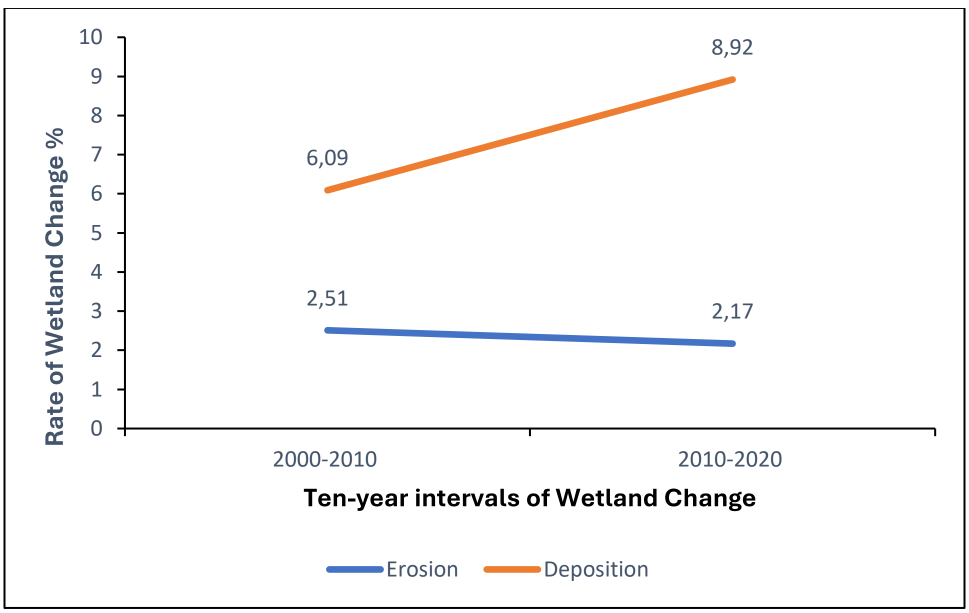


**Figure 4.9: Percentage fluctuations of erosion or deposition in a 20-year period.**

*Source: Researcher (2023).*

Figures 4.8 and 4.9 illustrate the spatio-temporal change statistical analysis of the wetland in Tembisa over the study period (2000 – 2020). The analysis presents opportunities to understand wetland dynamics in the study area and make informed conclusions. However, it is important to highlight that despite the usefulness of DEMs for earth observation studies as demonstrated so far, they cannot be used to identify specific types of waste types deposited in a landform. Therefore, to corroborate the projections on the DEMs, other data were required. To achieve this, historical and current images received from the studies participants were used. Figure 4.10 provides evidence that deposition illustrated in the above maps can be largely ascribed to CDW.


**Figure 4.10: CDW deposited into wetlands in Diepsloot and Tembisa.**

*Source: Fieldwork and NGO sources*

A close examination of the images in Figure 10 demonstrates that CDW can have massive effects on wetland ecosystems. Analysis of images above shows that CDW is the waste stream that dominates wetland dumping. This causes massive throttling which ultimately redirects river and wetland channels.

The images suggest that CDW is a heavy waste stream that cannot be easily eroded by natural drainage, thus corroborating projections of the DEM change detection maps. Based on the state of the vehicle in image 6 in Figure 8, CDW dumping in wetlands is a coordinated environmental crime. It provides some perspective on how the effects of CDW on wetlands, as shown in the DEMs, accumulated over the 20-year period without mitigation by the local authorities.

### 4.6. Discussion of results

Data and literature presented in this study suggests that the environmental performance of waste materials cannot be viewed only through the lens of toxicity. For instance, deposition of CDW into wetland ecosystems impairs the functions of this critical ecological feature, while also disrupting processes associated with aquatic species. Based on the results, it is particularly important to highlight that CDW affects wetlands in two ways including through its mineralogical profile and also its physicality. Through the embedded minerals, CDW can progressively contaminate wetland water, and ultimately the flora and fauna communities through bioaccumulation (e.g. Staunton et al., 2014). This is a massive negative effect, because aquatic organisms constitute an essential component of how wetlands function. Among other things, they assist in the recycling of critical nutrients required by other marine organisms in a wetland ecosystem (Kumar & Kanaujia, 2014). Data from this study suggests that the continued deposition of inert CDW in wetlands destroys the habitat for critical species such as the near endangered African Giant Bullfrog (*Pyxicephalus adspersus*). This finding presents significant faults in the conceptualization of waste only through the lens of toxicity.

Secondly, even in the absence of toxic minerals (since CDW is largely inert), CDW remains a potent environmental threat because of its voluminous and weighty nature. It impedes the ability of wetlands to erode and discharge water, and slowly cause infilling. This is illustrated by the DEMs presented in the results section where wetlands gained elevation through dumped CDW, and lost their ability to transport loads, ultimately contributing to seasonal floods. These findings match observations in a study by Mangoro & Kubanza (2023), where dumping of CDW disrupted the flood attenuation capabilities of wetlands causing massive flooding and deaths of minors.

Although participant perceptions provided in this study provide critical perspectives on how CDW can potentially affect wetlands, some critics are doubtful of qualitative data. This doubt is based on the view that qualitative data can often not be proved scientifically (Koch & Harrington, 1998). In this study, the use of DEMs to measure erosion and depositional processes provided an opportunity to quantitatively analyse wetland spatiotemporal changes over a 20-year period rather than rely on expert perceptions alone. From the DEMs, it is evident that massive deposition of waste occurred, particularly between 2010 and 2020, which put wetlands under significant threat. While the use of DEMs is flawed in the sense that it does not identify exact waste materials deposited in a given landform, corroborating data was acquired through ground truthing in the study area. Therefore, it can be confidently argued that CDW can have massive negative effects on the ability of wetlands to function optimally. In this perspective, this study argues that there is a need for urgent solutions to mitigate the effects of CDW on wetlands in South Africa and other countries facing massive illegal dumping. In the following section, the study is concluded with a series of recommendations on how to effectively manage CDW for the protection of wetlands.

## 4.7. Conclusion and Recommendations.

The findings of this study strongly suggests that the view of CDW as inert, and therefore not an immediate threat to the environment is incorrect. It is found in this study that CDW instantly affects the ability of wetlands to function normally. Rapid urbanization and expansion of the construction sector to meet the rising infrastructural needs across South Africa rapidly generates CDW. This suggests that in the absence of measures to mitigate the environmental problems associated with CDW, wetlands across South Africa will continue to disappear. Therefore, for South Africa to mitigate the environmental challenges associated with CDW, the following is recommended:

Establishment of tailor-made laws for CDW management in South Africa. The proposed new laws must clearly define the penalties associated with illegal dumping of CDW by any perpetrator. This is a crucial component of an effective waste legislation because it sets out the potential punishment associated with environmental crimes. Additionally, the proposed CDW management law needs to delineate the responsibilities of stakeholders, because this helps in tracing and tackling environmental crimes. Furthermore, enforced tailor-made laws encourage rapid transition to sustainable waste management practices, and evidence for this is replete in countries across the European Union such as Germany (Nelles et al., 2016). Additionally, this is important because it saves landfill space, reduces dumping, and limits the extraction of raw materials from the environment.

While legislation for CDW management is crucial in motivating sustainable behaviour, large-scale investment in cutting-edge and efficient CDW recycling machinery in South Africa is required. Like many developing countries, South Africa struggles to purchase, maintain, or operate CDW recycling plants (Mangoro et al., 2023). This problem arises from poor funding, negative attitudes, and general neglect of certain waste streams such as CDW (Mangoro et al., 2023). To mitigate the problems with funding, local municipalities can lobby national governments and multilateral organisations such as the United Nations Development Programme and the United Nations Environmental Programmes for funding or donation of required technologies. On a local level, funding can be sourced from the public and private sectors, and this could be done at regional level to avoid financial strain on the funders. The linkage between stringent and tailor-made law, and availability of recycling machinery creates opportunities for sustainable environmental and resource utilisation, thereby reducing strain on critical ecosystems such as wetlands that are typically targeted for dumping.

In unison with these measures, another strategy that can be deployed to effectively manage CDW includes the training of construction personnel in waste minimisation strategies, and this is necessary to limit the amount of waste that is illegally deposited in wetland ecosystems. As argued in the earlier sections, CDW is one of the largest waste streams in the global economy, which contributes about 40% of total annual global greenhouse gas emissions. In light of this, training personnel on how to manage waste in construction becomes imperative for those in the construction sector to achieve environmental sustainability. The training of construction personnel on how to manage CDW in all phases of construction is crucial because in bears direct environmental benefits such as waste reduction and preservation of finite natural resources.

Considering that wetlands in urban areas are usually located near informal settlements, it is crucial to establish a multi-stakeholder management programme where communities are central to decision-making. A shift from top-down management strategies currently adopted in developing countries like South Africa generally overlooks the role of local communities in area management, leading to the proliferation of environmental crimes by unscrupulous corporate entities.

There is a need for the establishment of an online based platform for information or data exchange. Poor or lack of communication between stakeholders in the construction industry generates opportunities for illicit waste economies (Mangoro et al., 2023). The online platform forms a community of organisations where information is given about location of construction sites, amount and nature of CDW generated as well as the shortest route to arrive there. This is very important because CDW can be used in new construction for original purposes or infilling foundations and avoid sand mining in aquatic environments.

## Paper No. 2
## Exploring Wetland Change in the Gauteng Province, South Africa[5]


### Abstract

The earth is currently enduring a period of unprecedented environmental change due to unsustainable anthropogenic activities. Urban environments across the world are the most affected by anthropogenic activities, especially forest clearance, construction, mining, agriculture, and dumping among other things. These activities have major environmental implications which can permanently alter affected areas. This study investigated land use and land cover changes in the informal settlements of Diepsloot and Tembisa in the Gauteng Province of South Africa and provided a predictive analysis of the state of wetland ecosystems in the two study areas by 2040. The study used processing software such as ArcGIS and ENVI to analyse Landsat images and assess spatiotemporal changes over time. It is argued that anthropogenic activities such as illegal dumping presents massive threats to the ability of wetlands to function or exist in the absence of change in human behaviour. The study found that construction and demolition waste dumping may lead to disappearance of wetlands in the study area by 2040.



**Keywords:** Construction and demolition waste, environment, wetland, geographical information system, Land Use and Land Cover Change, Anthropogenic activities.


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## 4.1. Introduction

The earth is currently enduring a period of unprecedented environmental change due to unsustainable anthropogenic activities in recent centuries (Chu & Karr, 2017; Malhi, 2017; IPCC, 2022). Several studies hold a consensus that anthropogenic activities since the Industrial Revolution have permanently altered the Earth's function in ways that can be measured in geological time scales (Gray-Cosgrove et al., 2015; Liboiron, 2015; Lalenti, 2020). Some of the anthropogenic activities accounting for global environmental change include mining, construction, agriculture, and forest clearance which contributes to carbon increased emissions and disruption of ecosystems (IPCC, 2022; Montt et al., 2018; Labaran et al., 2022). The environmental effects of anthropogenic activities in geological timeframes suggest that many human and non-human generations to come will be negatively affected by previous unsustainable anthropogenic processes. Drawing on this, the need for scientific comprehension of the effects of anthropogenic activities on environmental sustainability has reached a critical level (Mangoro & Kubanza, 2023).

Wetlands are some of the most affected ecosystems by anthropogenic activities, especially in developing countries where they are exploited for a plethora of purposes. Extant studies on wetlands reveals alarming levels of deterioration or disappearance due to unsustainable anthropogenic activities (Fitchett, 2017; Mangoro & Kubanza, 2023; Staunton et al., 2014; 2015). These studies highlight that wetlands are vanishing at a pace three times faster than forests (Ahidur, 2016; UN, 2018). It is further established that between 1970 and 2015, about 35% of world wetlands were lost due to unsustainable anthropogenic activities (WWF, 2018; UN, 2018), and these activities include construction, dumping, and agriculture (e.g., Staunton et al., 2015; Ahidur, 2016; Mandishona & Knight, 2022). The deterioration or disappearance of wetland ecosystems is a major catastrophe for human and non-human actors because they play several critical roles necessary for environmental equilibrium. For example, wetlands are linked with the function of providing habitat to approximately 40% of world's species, yet, due to unsustainable anthropogenic use there is high risk of the disappearance of approximately 25% of the associated vegetation (UN, 2018).

While a myriad of anthropogenic activities explains the phenomenon of rapid global wetland loss, construction and the related waste materials are rapidly becoming the leading cause (Staunton et al., 2015; Balud-Dajud et al., 2022; Ali-Khani et al., 2023; Mangoro & Kubanza, 2023). This is inextricably linked to rapid urbanization and economic expansion which necessitates high demand for infrastructure. Although urbanization and economic expansion are a critical component of human processes, infrastructural development produces massive and heterogenous volumes of construction and demolition waste (CDW) which can be risky to the environment in the absence of strong and coherent management systems (Luangcharoenrat et al., 2019; Zhang et al., 2023).

In the context of developing countries, there is a trend of rapid population agglomeration in low-income areas, typified by informal settlements for purposes of low-cost housing. In such areas, there is a consistent trend involving massive illegal dumping of CDW, particularly in riverine environments such as wetlands (Fitchett, 2017; Mangoro & Kubanza, 2023). There are strong indications that this rising problem will continue to grow in the next century. This view is emphatically supported by the United Nations which forecasts that the world population will reach 9.8 billion by 2050 and 11.2 billion by year 2100 (UN-DESA, 2017). Associated with this, it is projected that Sub-Saharan Africa (SSA) will reach a population of 2.4 billion by the year 2050 (UNEP, 2023), from the current estimated population of 1.21 billion (Statista, 2024). The realization of these estimations suggests imminent growth of construction activities, related waste (CDW), and the associated effects on ecosystems (UNEP, 2023).

Drawing from the above, this study investigated the effects of anthropogenic activities on wetlands in Diepsloot and Tembisa with a bias on construction and CDW. Specifically, this study adopted the use of satellite imagery (Landsat) to investigate land use and land cover changes (LULCC) in Diepsloot and Tembisa over a 20-year period from 2000 to 2020, to predict the state of wetlands in the study area by year 2040. (e.g., Fantaye et al., 2017; Jombo & Adelabu, 2023). In view of this, remote sensing can be an incredible technique to study the effects of anthropogenic activities on the environment in a given area, and this is crucial in decision-making long before disasters occur (Jombo & Adelabu, 2023). In the following section, a critical synthesis of extant literature is provided to understand the causes of wetland loss across the world.

### 4.1.2. Literature review

*4.1.2.1. Accounting for global wetland loss.*

Wetlands are a critical ecological feature that plays several important functions for both humanity and the environment (see Davidson, 2014; Hu et al., 2017). Among other ecological functions, wetlands attenuate floods, filter water, sequester carbon, and provide a habitat and water to aquatic species (Gebresllassie, et al., 2014; Zhu et al., 2023). By definition, wetlands are landforms encompassing areas of marsh, fen and peat lands. Additionally, wetlands also encompass areas with water and these can be natural or constructed, perennial or seasonal. Finally, wetlands can also be water bodies that are static, or in motion, with brackish or freshwater such as marine ecosystems with low tide and a depth below 6 metres (RCB, 1997).

This Ramsar definition is extensive and encompasses a wide range of types of water bodies to ensure comprehensive ecosystem management or conservation. Despite their documented significance, the world is currently enduring a global wetland loss phenomenon which started over a millennium ago (Davidson, 2014; Hu et al., 2017). Much of the factors accounting for wetland loss are associated with anthropogenic activities which span social, economic and political spheres, although natural factors have also been documented. Some scholars argue that over 50% of global wetlands have been lost since the beginning of the 20$^{th}$ century (Davidson, 2014).

Hu et al (2017) quantified the extent of global wetland loss per continent and the results of the study indicated a grim spectre on the future of global wetlands. The study found that the Asian continent lost 2.65 million km$^2$ of wetlands or 27% of the continental total. The study further observed massive wetland loss in South America, Oceania, and Europe. In these continents, South America lost approximately 32% of the total wetlands while the Oceania lost about 0.18 km$^2$, and Europe 45% (Hu et al., 2017).

Among the most common causes for wetland loss is climate change (Gebresllassie, et al., 2014; Hu et al., 2017; Penfound & Vas, 2023; Sithirith, 2015; Zhu et al., 2023). Zhu et al. (2023) revealed that geographically isolated wetlands, which typically have dense vegetation cover, are at risk of dying out because of climate change. In this study, it is argued that climate change can lead to the loss of wetland vegetation cover which could lead to loss of the ability to retain water or reduce run off. Climate change causes this disruption through extreme heat or low rainfall which ultimately results in wetland reduced water content and eventual wetland loss (Zhu et al., 2023). The effects of climate change will continue to threaten the existence of wetlands across the world. Using geographical information systems and remote sensing applications, Zhu et al. (2023) indicated that by the year 2099, the effects of climate change will likely lower down wetland water table by approximately 26cm (Zhu et al., 2023). By nature, the wetland water table is generally situated close to the surface which means that a 26cm decline will contribute to the eventual loss of more wetlands to poor recharge.

While climate change is known to cause significant wetland loss, much of the threats to wetlands is inextricably linked to anthropogenic activities (Dallut-Bajudetal, 2022). Agriculture is the largest known cause of wetland loss across the world (Gebresllassie et al., 2014; Mandishona & Knight, 2022; OECD, 1996), accounting for about 25% of this phenomenon (Dallut-Bajudetal, 2022). Cases of exploitation of wetlands for agriculture have been reported around the world, and this is mostly in developing countries (see Mandishona & Knight, 2022). For example, in the southwestern parts of Ethiopia, the government and farmers are involved in the drainage of wetlands for agriculture and other unspecified activities (Gebresllassie et al., 2014). Similarly, cases of wetland use for agriculture have been documented in parts of Zimbabwe where communal farmers deploy different tilling methods such as ox-drawn ploughs or hand-held tools like hoes (Mandishona & Knight, 2022). The use of wetlands for agricultural purposes or other ecosystem services eventually leads to their disappearance or permanent disruption of functions.

Another anthropogenic activity accounting for wetland loss across the world is urbanization. It must be highlighted that developing countries are urbanizing faster than developed countries, and this coincides with massive loss of wetlands. Studies by Dallut-Bajud et al

(2022) estimate that urbanization is responsible for 16.8% of global wetland loss. Urbanization is typified by development activities such as the construction of roads, buildings, and flood control systems (Gebresllassie et al., 2014; Davidson, 2014; Sithirith, 2015; Zhu et al., 2023). Construction activities generate impervious surfaces which reduces the rate of water infiltration and increase surface run off. Ultimately, construction activities reduce wetland water recharge or water retention capacity of wetlands (Zhu et al., 2023). Additionally, urbanization promotes infilling of wetlands for purposes of construction as documented in Ethiopia and Cambodia (Gebresllassie, et al., 2014; Sithirith, 2015), while this has been happening in Europe, America, and Asia for centuries (Zhu et al. 2023). Therefore, although urbanization can be an indicator of social and economic prosperity which developing countries yearn for, it produces a binary of success and environmental deterioration.

Urbanization is a tremendous source of wetland deterioration as discussed above, and yet; it has an additional effect of encouraging pollution in the event of poor environmental management systems. Some studies associate increasing urbanization with wetland pollution because population agglomeration results in fast-paced products of construction waste among other waste streams (e.g., Sithirith, 2015; Fitchett, 2017; Mangoro & Kubanza, 2023). However, cases of wetland pollution and urban waste also occur in developed countries. Staunton et al (2015) documented cases of wetland pollution through CDW in the Republic of Ireland. Repeated pollution of wetland ecosystems in the Republic of Ireland led to significant alteration of wetlands, and in some cases, a total disappearance. In addition to pollution from urbanization, there are several cases where there is massive spillage of raw sewage, causing massive wetland deterioration.

This practice diminishes the ability of wetlands to function optimally due to the deposition of human waste and the associated pathogens which can alter water quality and aquatic life (Wetlands International, 2010). From this literature, it is clear that while urbanization produces more economic prosperity, it leads to massive environmental degradation in the absence of effective governance systems.

In some countries, the loss of wetlands has been linked to a lack of clear and coherent laws governing aquatic ecosystems (Gebresllassie et al., 2014; Sithirith, 2015). A lack of clearly articulated policy together with weak institutions heightens the vulnerability of wetlands because this combination generates confusion within the associated sectors. For instance, Cambodia and Ethiopia, the environmental law does not define wetlands and this results in sectors formulating their own meanings which suit their agendas (Gebresllassie et al., 2014; Sithirith, 2015). These problems are exacerbated by a lack of institutional capacity to management wetlands. Cases of shortage of manpower, funding, and technology for sustainable wetlands conservation are replete in developing countries (Gebresllassie et al., 2014). Lack of manpower emanates from the absence of training programs for wetlands conservation or management at institutions of higher learning (Gebresllassie et al., 2014).

*4.1.2.2. Accounting for wetland loss in South Africa.*

Wetland loss is a phenomenon in South Africa that emerged several decades ago. Existing aquatic studies in South Africa reveal that wetland loss rose from 45% in the 1980s to about 65% in the 1990s (Whyte & Shepherd, 1999), while other studies peg it at almost 50% in the last two decades (Adeeyo et al., 2022; SANBI, 2013). More recent studies have established that there are about 300,000 wetland ecosystems remaining in South Africa (Adeeyo et al., 2022). It is further argued that of this number, 48% is at high risk of further disruption, while 12% are now endangered and 5% are prone to human exploitation whereas, 35% are generally at low risk (Adeeyo et al., 2022). The major cause of this phenomenon is the growing number of unsustainable anthropogenic activities (Whyte & Shepherd, 1999; Rivers-Moore & Cowden, 2012; Adeeyo et al., 2022).

One of the major anthropogenic activities accounting for wetland loss in South Africa is mining operations. For example, studies in some parts of South Africa such as Mpumalanga Province, suggest that mining activities (e.g., for coal) have destroyed vast tracts of wetland areas (Van Vuuren, 2014; WRC, 2016). This is because wetlands are generally situated in low lying areas where miners also prefer to undertake open case mining due to its relative low cost in comparison to other methods (Van Vuuren, 2014; WRC, 2016). Earthworks involved in mining processes negatively affect the general hydrology near mining sites, leading to disruption of associated wetlands through changes in water recharge trends (Water Studies Commission, 2016). However, mining activities in South Africa have also been linked with wetland loss through deposition of polluted water which ultimately affect the integrity of these ecosystems and the related biodiversity (Van Vuuren, 2014).

In addition to mining activities, wetland loss in South Africa is also linked to invasive alien species such as giant and common reeds, water fern, wattle, hyacinth, and velvet mesquite among others (Solitude Lake Management, 2021). Species like velvet mesquite (*Prosopis velutina)* have significant negative impact on wetlands, associated biodiversity, recharge ability, and on human livelihoods (Solitude Lake Management, 2021). Similarly, some studies argue that wattle (silver, long weaved, and black wattle) uses excessive amounts of water, resulting in disruption of wetland ecosystem functionality (AgriOrbit, 2020). Therefore, if a wetland is overwhelmed by alien vegetation, excessive evapotranspiration happens, leading to massive water consumption which in turn also affects groundwater recharge (Adeeyo et al., 2022). Drawing on the above, it is apparent that invasive alien species are a massive source of wetland loss in South Africa.

Although the above presents massive threats to wetlands in South Africa, other anthropogenic activities like agriculture are also a leading cause (Grundling et al., 2011; Sinthumule and Netshisaulu, 2022). For instance, crop farming, plantations, and irrigation schemes cause environmental deterioration, and dwindling of wetlands in areas of South Africa such as KwaZulu Natal Province and Limpopo Province (Grundling, 2011; Sinthumule & Netshisaulu, 2022). Furthermore, communities in rural areas understood that some wetland ecosystems have rich soils that could provide adequate nutrients to their crops, which results in drainage of water to generate conditions suitable for some crops such as maize (Grundling, 2000). The process of draining water out of wetlands erodes their ability to provide services which include recharge of rivers and provision of habitat. This problem grows in significance considering that only 11% of different wetland types in South Africa is protected by the Ramsar Convention (Adeeyo et al., 2022). Furthermore, a study by Skowno (2018) indicates that only 6% of wetlands located in inland areas are protected, and they are found in conservation areas such parks or reserves. This present major problems because due to decreased rainfall, wetlands are likely to be targeted for subsistence farming in South Africa.

In addition to the above, wetland loss in South Africa is also a result of construction-related activities (Mlambo, 2018; Adeeyo et al., 2022; Sinthumule & Netshisaulu, 2022). Due to a rise in population in South African cities, there is also a rising demand for low-cost housing as a result of the steep cost of accommodation (Mlambo, 2018). As a result of this, informal settlements are developing rapidly especially in the outlying areas of big cities, typically on catchment areas such as wetlands purposely left undeveloped by city planners for environmental concerns. However, it is imperative to note that while low-cost housing such as makeshift shelters accounts for much of the construction on wetlands in South Africa, even large corporations are often involved in such environmental crimes. For example, a large corporation was fined for building a property on a wetland in Centurion in the Gauteng Province which resulted in wetland loss (Kings, 2018). Dam construction also accounts for wetland loss in South Africa (Schuyt, 2004). Wetlands are prime targets for dam construction in South Africa because they are usually found in areas that are suitable for dam construction (Collins, 2006). Dam construction therefore has far-reaching consequences because it results in total wetland loss of major disruption of their ability to perform ecosystem services (Collins, 2006).

Although there seem to be abundance of studies on wetland ecosystems in South Africa, there is a shortage of comprehensive assessments to adequately inform city planning. This is because existing studies typically focus on a selected wetland due to the perceived associated costs of conducting assessment on multiple sites (Rivers-Moore & Cowden, 2012). In this study, at attempt is made to narrow this gap by focusing on land use and land cover changes in Diepsloot and Tembisa informal areas in order to determine the long-term impacts of CDW on wetlands. The significance of this study lies in the fact that it provides data and pointers crucial for mitigation of wetland loss before it happens.

### 4.1.3. Materials and methods

*4.1.3.1 Study Context*

Diepsloot (25.9424° S, 28.0201° E) and Tembisa (26.0129° S, 28.2233° E) are low-income settlements located in the vicinity of the boundary between the Johannesburg Metropolitan Municipality and the Ekurhuleni Metropolitan Municipality. The settlements are characterized by formal and informal sections built along the Jukskei River catchment area comprising a dense network of perennial water bodies. The Jukskei River catchment wetlands in the region and their riparian zones form a habitat for several critical wildlife species which include the near-endangered African Giant Bullfrog (*Pyxicephalus adspersus*), and the grass owl (*Tyto longimembris*) (Yetman & Ferguson, 2011; Mangoro & Kubanza, 2023). The study area has experienced a massive surge in environmental crimes in the last 20 years, particularly in the form of illegal dumping in wetland areas which form habitat for various wildlife species (Fitchett, 2017). Specifically, there is intense illegal dumping of household waste (Mangoro & Kubanza, 2023) and construction waste (never remediated), which has significantly diminished the quality of wetlands in the area. This study maps out the effect of anthropogenic activities on wetlands in the research area in current and future contexts.

*4.1.3.2. Image acquisition*

Prediction of potential future impacts of anthropogenic activities on ecosystems is dependent on an analysis of previous and current land use activities. This study uses the period from the years 2000 to 2020 on a ten-year interval as the benchmark. This is because population growth and rapid infrastructural development in the area transpired during this period (Mangoro & Kubanza, 2023). Satellite imagery of the study area in these twenty years can be used to investigate and measure topographic events affecting ecosystems. The outcome of this data manipulation and analysis can be used to predict the state of given ecosystems (in this case wetlands) in a selected period in the future (Jombo & Adelabu, 2023). In this paper, a twenty-year period from 2020 to 2040 was selected.

To measure topographic events from the years 2000 to 2020 on the selected wetlands, Landsat images were used. Landsat images were acquired from the United States Geological Survey (USGS) Earth Explorer image repository (http://earthexplorer.usgs.gov). All the images used in this study have Path = 169 and Row = 78 and they are all cloud free to enhance visibility. Landsat images are derived from different satellites depending on the chosen period of study. Images for the year 2000 were taken by the USGS through Landsat TM 4/5. Landsat TM 4/5 operated from 1982 to 2012 and it operated on a 16-day repetitive sequence which is referenced to the World Reference System-2 (USGS, 2018).

Furthermore, the adopted dataset for 2010 and 2020 was from Landsat 8 (ETM+). Landsat 8 was launched in February 2013, and it was equipped with the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) instruments (Dibs et al., 2023). Images used in this study were drawn from both the Landsat ETM+ sensor and the Landsat OLI sensor. The OLI measures through visible near infrared and shortwave infrared portions of the spectrum (USGS, 2013; Dibs et al., 2023).

Radiometric calibration was applied to each image, and then atmospheric correction using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube (FLAASH) module in ENVI (v5.4) was applied. The three images were mosaicked separately to produce a single image for each year in the ENVI software. Clipping was then done to produce the study area (Diepsloot and Tembisa), shapefiles that had been previously created were used in this regard. The gap-fill application in ArcGIS Pro 3.1.2. was utilised to correct the scan line failure by filling the gaps on the Landsat 7 ETM+ images. After all these processes, the images were ready for classification.

*4.1.3.3. Reference Data*

Pre-processed Landsat datasets were visually interpreted to obtain the reference dataset. Randomly selected yet well-distributed training areas were selected to ensure full representation of each class. Point features were digitised with class labels for each class and this was done using ArcGIS on the mosaicked images. The point features of each image were then loaded on Google Earth Pro imagery (http://earth.goggle.com/) accessed on 20 December 2023. The temporal data was used to evaluate the regularity of the points. The points that were found in differing areas of their LULCC were eliminated. Pixel values were then extracted in ArcGIS using the feature extraction tool. For each class, the sample points created ranged from 200 to 350, and the extracted pixel values for each class were divided randomly into training (70%) and testing (30%) datasets. The training dataset was used to train the classifier while the testing dataset was used to validate the classification accuracy.

#### *4.1.3.4. Image classification*

For the LULCC classification process, 4 classes were selected for Diepsloot (namely wetlands, vegetation, bare land and the urban built up), while 5 classes were selected for Tembisa (namely wetlands, bare land, vegetation, cultivated areas and built-up areas). The Random Forest (RF) software was used in this study as a classification tool to create LULCC maps of the multi-temporal images. It is an ensemble learning algorithm that is centred on decision trees (DT). The classifier operates by creating a set of DT during model training and produces the class with the greatest appearance for classification or mean estimation for regression (Wessels et al., 2016). The RF classifier used for this study involves a random selection of features or a combination of features at each node to grow a tree. The Gini coefficient was used for attribute selection, and it measured the impurity of an attribute in relation to the classes (Canty, 2014). On a new training sample, each tree is grown to the maximum depth using a combination of features. When the trees are fully grown, they are not pruned, and this makes the classification output less variable and more stable. (Jensen et al., 2009). The number of features used at each node to generate a tree and the number of trees to be grown are two user-defined parameters required to generate a random forest classifier (Al-Fares, 2013). At each node, only selected features are searched for the best split (Al-Fares, 2013).

#### *4.1.3.5. Accuracy Assessment*

Classification accuracy is the most critical feature to assess the reliability of the final map outputs and it encompasses statistical estimates obtainable from the classification output and an independent reference dataset to calculate the probability of the classified output. According to Foody (2002), accuracy assessment guarantees classification quality and user confidence in the product. It is empirically determined by selecting a sample of pixels from the imagery and examining their labels against classes defined from the reference data. The proportion of pixels from each class correctly labelled by the classier in the image is estimated so as the percentage of pixels from each class inaccurately labelled into every other class. These results are articulated in a tabular form known as the confusion matrix (Lillesand et al., 2015). The confusion matrix measures the following metrics, overall accuracy, user's accuracy, producer's accuracy and the kappa coefficient (Guerschman et al ,2003).

*4.1.3.6. Change Detection*

In this study, change detection was executed using the change detection statistics tool in ENVI 5.4. This was done to examine the shifts in the various LULCC classes, particularly the wetland areas. The outcome of the examination was three maps 2000, 2010, and 2020 respectively. The statistics report included a class-for-class image disparity and its main focus is on the initial state classification shifts that is, for every initial state class, the examination detects the classes in which those pixels changed in the final state image. The classified thematic maps are cross tabulated on a pixel-to-pixel basis to generate overall change maps and change matrices. The change statistics were expressed in two forms that is, area in hectares and percentage of the total change. These statistics were analysed to examine the nature and magnitude of LULCC change in the Diepsloot and Tembisa study areas during the 20-year period.

*4.1.3.6. Prediction of wetland change*

To compute the forecast models and calculate the wetland changes for 2030 and 2040, the transition matrix for 2000 to 2010 was generated, and then the integrated CA-ANN method in the MOLUSCE plugin that is embedded in the QGIS 2.18.15 version. The plugin is an open source for QGIS 2.0 to 2.99, any version after this, is incompatible. Numerous studies have revealed that the CA-ANN model more superior and robust in predicting LULCC in comparison to other models such as Marcov and linear regression (Abbas et.al, 2021; Rahman 2017). For the future simulations the 30 x 30m resolution and the WGS 84 Co-ordinate system was retained. Other variables that were utilised included slope and distance from the settlements, rivers and roads, and the Digital Elevation Model (DEM) was considered. these variables are commonly utilised to simulate LULCC as they generate reproducible data on the natural and anthropogenic disturbances in the LULCC processes.

To evaluate the reliability of the future simulating model, a validation process was implemented using a comparative analytical procedure of the kappa coefficient and the percentage of correctness in the MOLUSCE plugin. To validate the performance of the CA-ANN model, the researcher compared the actual 2020 LULCC data generated using the Landsat imagery and the RF classier with the one simulated for the same year generated using the CA-ANN algorithm.

## 4.2. Results and analysis

### *4.2.1. Study Area 1, Diepsloot Township, Johannesburg Metropolitan Municipality.*

Increase in urbanization and associated anthropogenic processes such as construction, cultivation and waste dumping have profound ramifications on LULCC in a given geographical location. This is evident in the two study areas (Diepsloot and Tembisa) where five classes of features namely wetlands, vegetation, and cultivated areas and bare land were classified. Figure 4.11 provides an LULCC map tracking topographical changes between year 2000 and 2020.

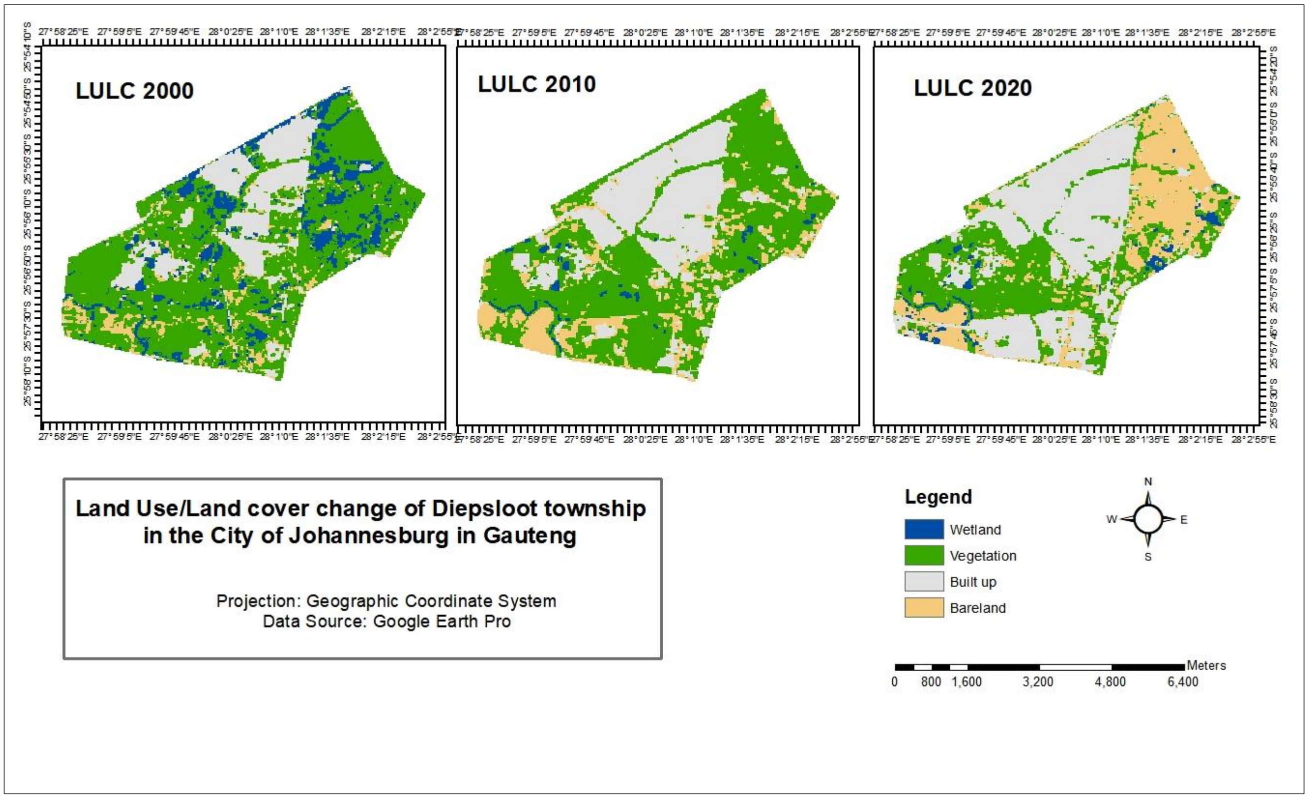


**Fig. 4.11:** LULCC trends in Diepsloot between 2000 and 2020

*Source: Researcher (2023)*

In Figure 4.11, a dramatic increase in buildings can be observed in Diepsloot which suggests rapid construction processes to accommodate increased population of approximately 350 000 (World Population Review, 2024). A rapid increase in built up areas in a location replete with aquatic ecosystems suggest that massive infilling transpired within this period, and this is corroborated by the fast disappearance of wetlands (represented in blue). Furthermore, construction processes result in land clearance and vegetation loss, and an increase in bare land as illustrated in Figure 4.11. The LULCC transpiring in Diepsloot between 2000 and 2020 are graphically and quantitatively illustrated in Figure 4.12 and Table 4.4 and 4.5.

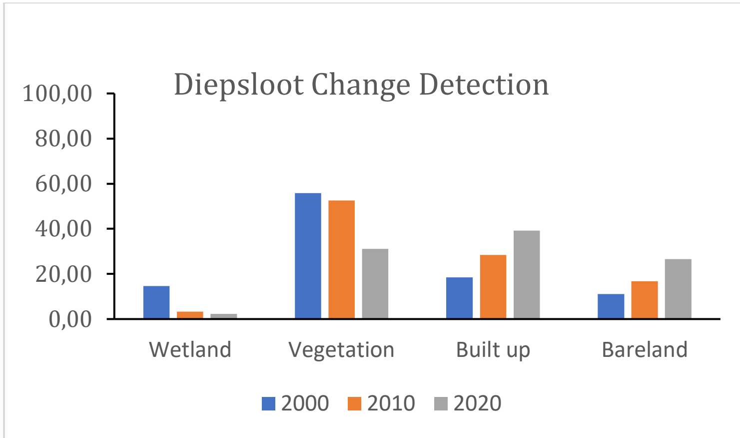


**Fig. 4.12: Summary of Land Use and Land Cover Change in Diepsloot.**

*Source: Researcher (2023)*

Immense transformation in LULCC in Diepsloot are clearly noticeable in Figure 4.12. To illustrate these changes, Table 4.4. illustrates the area of land covered by the four selected feature classes in this study. It can be observed that wetland cover diminished from 368.82 hectares in year 2000 to 56.25 hectares in 2010, and 18.9 hectares in 2020, suggesting an overall percentage drop from 14.58% to 2.22% (Table 4.5.). Furthermore, changes can be seen with vegetation cover which dropped from approximately 1413.09 hectares in 2000 to 786.78 in 2020, representing a drop from about 55.85% to 31.09% in 2020 (Table 4.5).

Table 4.4: Trends in area covered by selected features.

| **Diepsloot (area in ha)** | | | |
|---|---|---|---|
| | **2000** | **2010** | **2020** |
| **Wetland** | 368,82 | 56,25 | 18,9 |
| **Vegetation** | 1413,09 | 1330,2 | 786,78 |
| **Built up** | 465,93 | 719,19 | 990,81 |
| **Bare land** | 282,51 | 424,71 | 670,86 |
| **Total** | 2530,35 | 2530,35 | 2530,35 |

Table 4.5: Percentage Land Use and Land Cover Change in Diepsloot.

| Diepsloot (%) | | | |
|---|---|---|---|
| | **2000** | **2010** | **2020** |
| **Wetland** | 14,58 | 3,24 | 2,22 |
| **Vegetation** | 55,85 | 52,57 | 31,09 |
| **Built up** | 18,41 | 28,42 | 39,16 |
| **Bare land** | 11,16 | 16,78 | 26,51 |

From Table 4.4., changes in area covered can also be observed with built up areas which increased from 465,93 in 2000 to 990.81 hectares in 2020, representing an upward trend of 18.41% to 39. 16% (Table 4.5.). Lastly, the area covered by bare land demonstrably increased from 282,51 hectares in 2000 to 670.9 hectares in 2020 – a change from 11.16% to 26.51% at present, suggesting massive vegetation clearance to pave way for human activities in future.

### 4.2.2. Study Area 2: Tembisa Township, Ekurhuleni Municipality.

Figure 4.13 presents a land use landcover change map for Tembisa between 2000 and 2020. The impact of anthropogenic processes on LULCC is clearly noticeable in the twenty-year period.

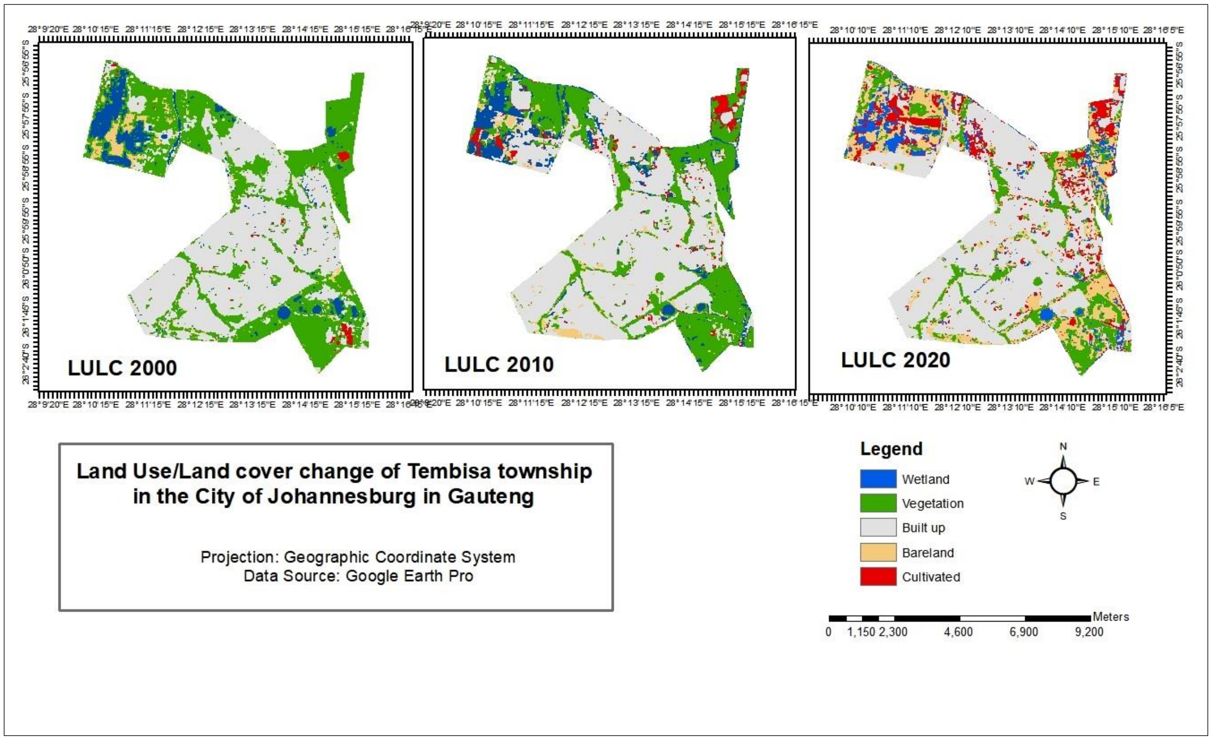


**Fig. 4.13: LULCC trends in Tembisa between 2000 and 2020.**

*Source: Researcher (2023)*

Firstly, there is a sharp increase in built areas as is the case in Diepsloot, suggesting increasing urbanization in Tembisa. In terms of wetland cover, a similar trend as in Diepsloot can also be observed in Tembisa where wetlands rapidly deteriorated or disappeared between 2000 and 2020 due to increasing unsustainable anthropogenic activities such as construction (suggesting massive wetland infilling). However, unlike in Diepsloot, LULCC in Tembisa is also characterized by cultivation for agricultural activities in wetland areas between 2000 and 2010. In addition to this, it can be observed that there is also an increase in bare land in Tembisa between 2000 and 2010, especially in the central and south-eastern sections due to increase in pressure on land in the period. However, the vegetation appears to regenerate in the decade leading to 2020, possibly due to municipal conservation works which began around 2008 (City of Ekurhuleni Municipality, 2008).

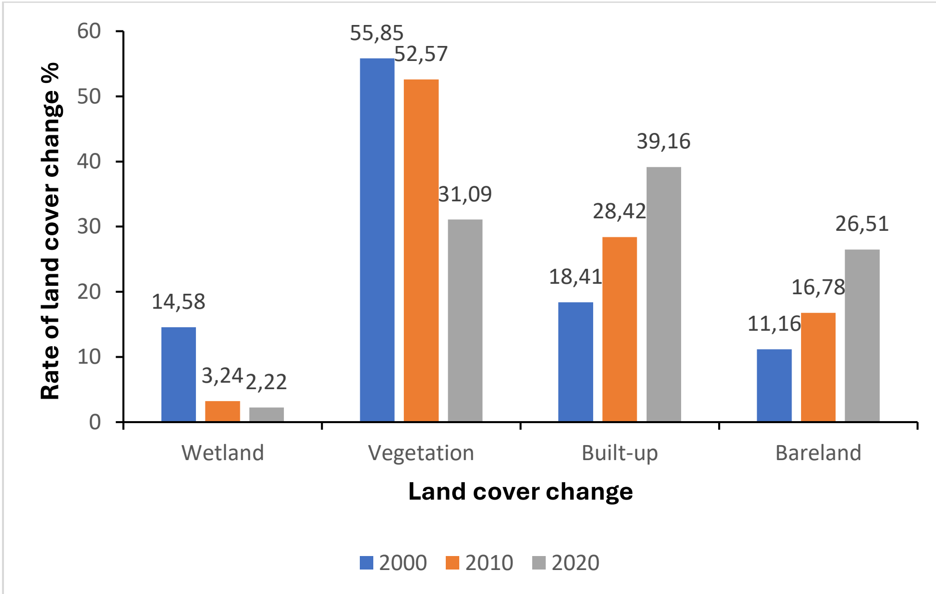


**Fig 4.14: Summary of Land Use and Land Cover Change in Tembisa.**

*Source: Researcher*

Figure 4.14 captures LULCC in Tembisa, and a decrease in wetland area can be observed. Table 4.6. shows that wetlands decreased from 468 hectares in 2000 to 227.88 in 2020, representing a drop from 8.65% to 4.21% in 2020. Furthermore, vegetation cover decreased from 2119.59 hectares in 2000 to 227.88 in 2020 (Table 4.6), indicating a decline from 39.17% to 16.93% (Table 4.7). In contrast, the built-up area increased from 2475.27 hectares in 2000 to 2752.38 in 2020. In addition to this, there is also an increase in bare land by up to 16.81%, and this figure could have been higher in the absence of municipal conservation programs such as clean-up and rehabilitation (City of Ekurhuleni Municipality, 2023). Finally, there is an increase in land cultivation for agriculture from 58.41 hectares in 2000 to 203.85 in 2010, and 517.77 hectares in 2020 (Table 4.6), representing an increase from 1.08% to 9.53% at present (Table 4.7).

Table 4.6: Trends in area covered by selected features.

| Tembisa (area in hectares) | | | |
|---|---|---|---|
| | **2000** | **2010** | **2020** |
| **Wetland** | 468 | 384,12 | 227,88 |
| **Vegetation** | 2119,59 | 1456,56 | 735,93 |
| **Built up** | 2475,27 | 2573,73 | 2752,38 |
| **Bare land** | 289,89 | 249,75 | 959,49 |
| **Cultivated** | 58,41 | 203,85 | 517,77 |
| **Total** | 5411,16 | 4868,01 | 5193,45 |

Table 4.7: Land Use and Land Cover Change in Tembisa.

| Tembisa (%) | | | |
|---|---|---|---|
| | **2000** | **2010** | **2020** |
| **Wetland** | 8,65 | 6,27 | 4,21 |
| **Vegetation** | 39,17 | 32,43 | 16,93 |
| **Built up** | 45,74 | 49,04 | 52,53 |
| **Bare land** | 5,36 | 8,31 | 16,81 |
| **Cultivated** | 1,08 | 3,95 | 9,53 |

The statistics and illustrations in this section suggest that anthropogenic activities have massively affected LULCC in Tembisa in the last 20 years. While these results are informative for decision makers in South African metropolitans, much can be further derived to improve the current state of environmental governance. In this study, the statistical trends were used to predict future LULCC in the research area up to year 2040.

### *4.2.3. Prediction of Land Use Land Cover Change in Diepsloot and Tembisa between 2020 and 2040.*

Prediction of future environmental trends have become a critical urban management tool across the world (Jombo & Adelabu, 2023). Predictions are critical because they can be used to mitigate environmental disasters before they happen, and this is particularly important in the period of rapid climate change due to anthropogenic activities. Based on the statistical analysis of LULCC in Diepsloot and Tembisa provided above, Figure 4.15 and Figure 4.16 provides an illustration of potential environmental events by year 2040.

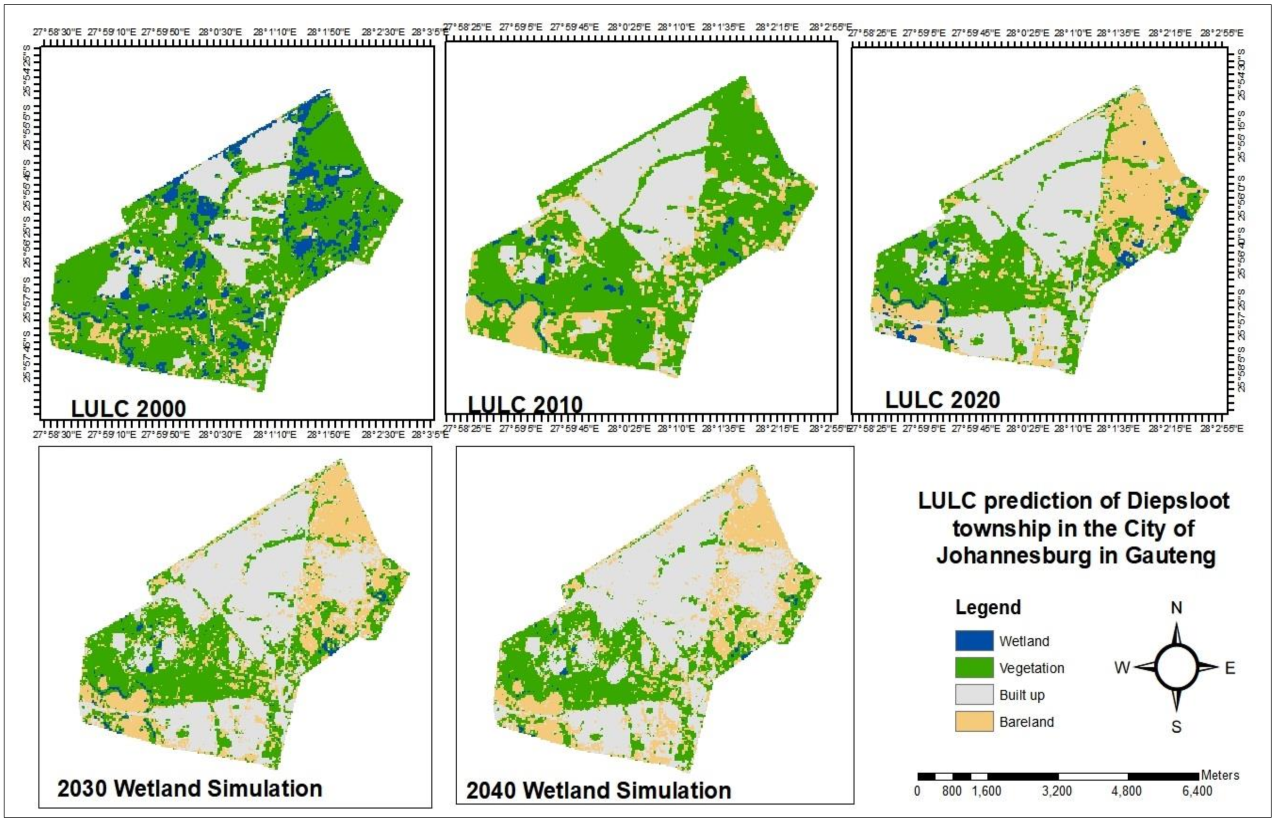


**Fig 4.15: Simulation land use and land cover change in Diepsloot by 2040.**

*Source: Researcher*

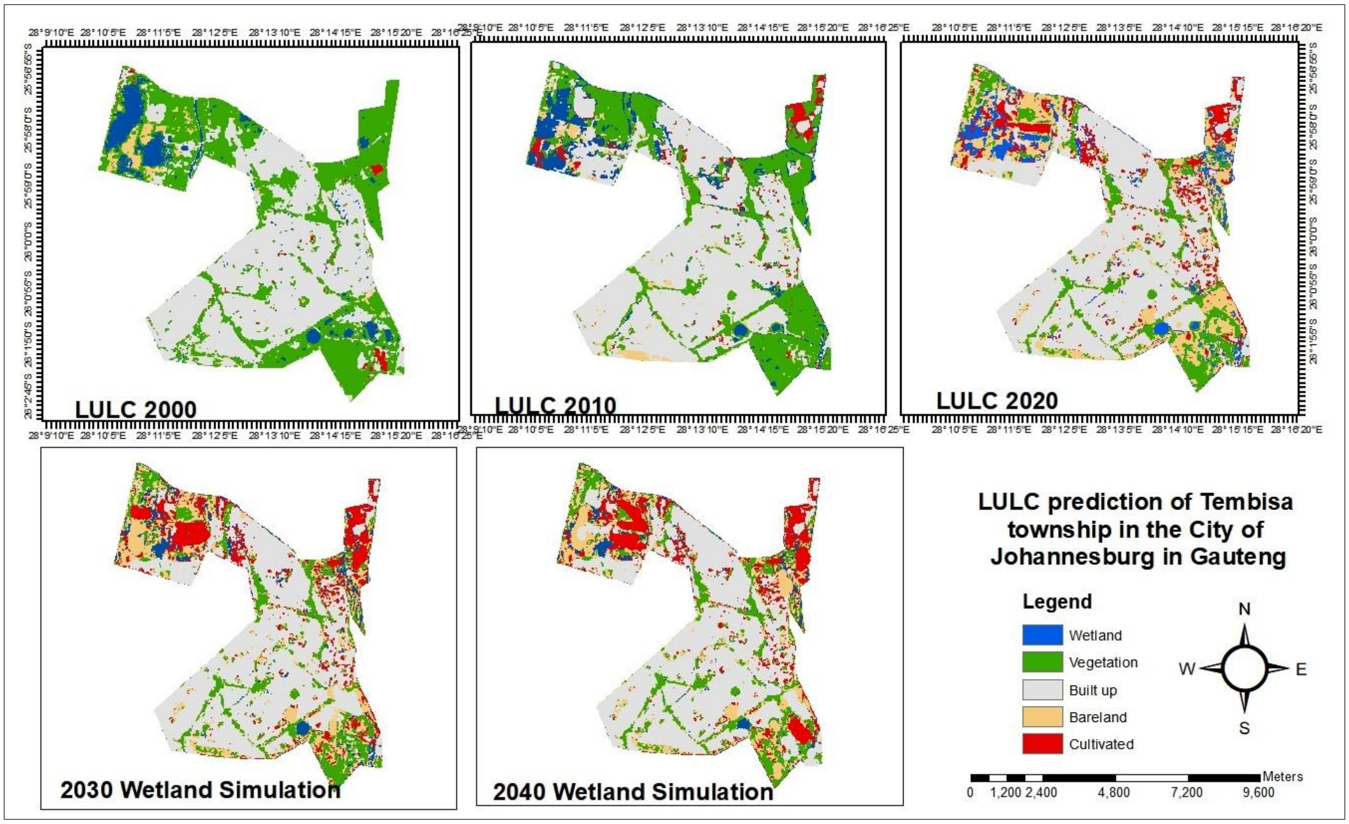


**Fig 4.16: Simulation land use and land cover change in Tembisa by 2040.**

*Source: Researcher*

In Figure 4.15 and 4.16, it can be observed while all selected feature classes will continue to be affected by anthropogenic activities between 2020, 2030 and 2040, wetland loss will be the greatest. In Table 4.8, it can be observed that by 2040, only 9.54 hectares of wetland cover will remain in Diepsloot, and 107,01 hectares in Tembisa.

Table 4.8: Land Use and Land Cover Change trends in Diepsloot and Tembisa by 2040

| | **2000** | **2010** | **2020** | **2030** | **2040** |
|---|---|---|---|---|---|
| **Diepsloot** | 368,82 | 81,9 | 56,25 | 36,72 | 9,54 |
| **Tembisa** | 468 | 384,12 | 227,88 | 159,39 | 107,01 |

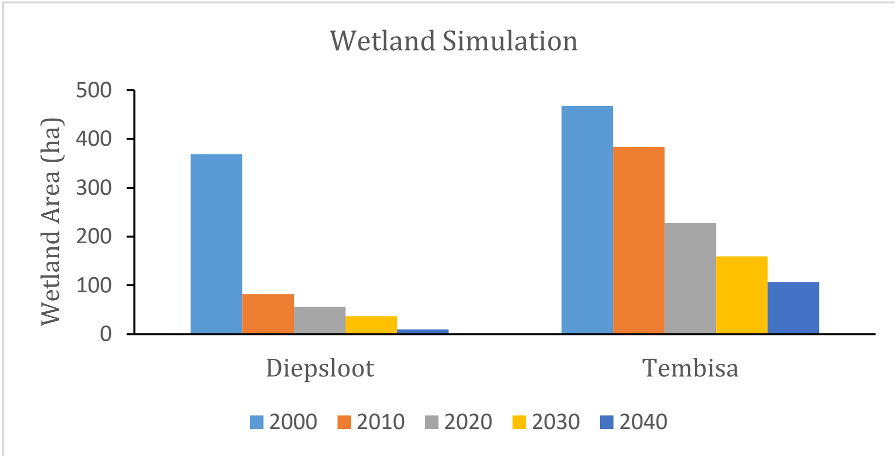


**Figure 4.17: Graphical illustration of Land Use and Land Cover Change in Diepsloot and Tembisa by 2040**

*Source: Researcher*

An increase in built up area is inevitable based on the increase in population between 2000 and 2020. This is supported by the fact that urban housing has increased significantly, which will probably drive people into informal settlements such as Diepsloot and Tembisa, where construction is illegally done on wetlands. To generate land for illegal construction, wetlands are targeted for infilling, especially with construction and demolition waste. The use of construction waste for infilling wetlands has precedence in both areas. Figure 4.18 provides further evidence.

**Figure 4.18: Construction and demolition waste throttling wetlands in Diepsloot Reception Area, Extension 6 and Tembisa.**

*Source: Willem Snyman – Fresh. NGÔ and Greater Kyalami Conservancy, 2023, 2024*

## 4.3. Discussion

Land use land cover change in the study areas from year 2000 to 2020 indicate events consistent with overconsumption, population growth and unregulated urbanization in South African metropoles. There is a sharp decrease in vegetation cover in both areas, and consequently an increase in bare land required for anthropogenic activities such as cultivation and construction. This is consistent with existing literature on vegetation loss across South Africa due to human activities (SA Government, 1996; Mclean et al., 2016; Zungu et al., 2020). While this is a noteworthy LULCC observation on environmental degradation, much of the catastrophic effect was on wetland ecosystems which were targeted for illegal construction activities in both study areas.

What is of great significance to note in this regard is that construction over wetlands is only a product of organized environmental crimes involving massive importation of CDW from high income areas in the northern areas of Johannesburg (e.g., Bega, 2018; Styger, 2019). Much of the legally regulated construction processes in the last 20 years have occurred in the high-income suburban areas in northern and northwestern areas of Johannesburg. However, due to a variety of reasons, among them a shortage of landfills in the northern areas (e.g., Simelane, 2017), much of the CDW resulting from the construction processes has been illegally transported and disposed in wetlands around Diepsloot and Tembisa (Bega, 2018). Due to the rising trend of 'construction mafia' and land grabs in South Africa (e.g., Nyangiwe et al., 2023), unscrupulous infilling of wetlands with CDW is done to generate dry land for illegal construction. Similar trends were observed in several studies across South African provinces such as Gauteng, Western Cape and KwaZulu-Natal (Kings, 2013; Moagi, 2018; Ngcuka, 2021; Mangoro & Kubanza, 2023). Existing literature, mainly from newspapers suggest that illegal dumping of CDW in wetlands is a phenomenon that has occurred for several decades to date (e.g., Bega, 2018), and this is corroborated by the LULCC maps provided in this study.

Using the land use trends from year 2000 to 2020, this study also investigated the potential state of wetland areas in the research area by 2040. Based on these trends, a quantitative analysis, using remote sensing techniques, this study found that wetlands in both Diepsloot and Tembisa are most likely to almost totally disappear due to infilling and subsequent illegal construction. Disappearance of wetlands due to infilling with CDW is recorded in some parts of the world (e.g., Staunton et al., 2014; 2015). The disappearance of wetlands carries negative implications on various flora and fauna including bullfrogs and grass owls, among others. For humanity, wetland pollution can cause severe health problems for local and downstream communities (Mangoro & Kubanza, 2023). Additionally, humanity will also be affected because wetlands provide ecosystem services such as water supply which is critical in a water scarce region like South Africa, and provision of space for cultural activities (e.g., Mandishona & Knight, 2022).

However, it must be highlighted that while CDW is the major cause for wetland disappearance, anthropogenic activities such as cultivation (in Tembisa), also negatively affect the ecosystems. It is important to note that cultivation disrupts the organic function of wetlands rather than completely consuming them into total disappearance. Furthermore, although CDW is the largest threat to wetlands in Diepsloot and Tembisa, household waste from the case studies also presents threats (see Fitchett, 2017; Mangoro & Kubanza, 2023). However, it is important to note that there are constant clean-up programs by NGOs like Greater Kylami Conservancy (Gekco), FreshNGO and Wotiftrust, Boombadotmobi among many others (e.g., Mosina, 2016; Fourways Review, 2017; Kirk, 2017). Clean up programs on wetlands in the study areas specifically target household waste because of its relative ease to manipulate and move. Heavy and ubiquitous waste such as CDW is deliberately ignored because it requires massive capital investment and other logistical arrangements. Based on this, wetlands will continue to face the threat of total disappearance as illustrated in the simulation provided in this study.

### 4.4. Conclusion

This study provides a comprehensive analysis of LULCC in Diepsloot and Tembisa between 2000 and 2020. It is demonstrated that anthropogenic activities such as illegal dumping and construction can cause massive environmental damage, particularly in the case of wetlands. Furthermore, a predictive investigation of the state of wetlands in the study area from 2020 until 2040, indicates that if the current trend of human activities continues, wetlands in Diepsloot and Tembisa are likely to almost disappear. This is particularly because of construction and demolition waste which is used to infill wetlands, and subsequent construction of makeshift housing which effectively consumes them. The findings of this study provide a basis for decision making such as mitigation of environmental disasters such as flooding and destruction of property before they happen.

On the basis of the findings of this study, a number of recommendations are made to reduce the pressure on wetlands. First, there is need for wetland delineation and installation of steel barriers to discourage direct deposition of construction and demolition waste and other waste streams. Second, there is need for community education on the protection of wetlands and the environment at large. Furthermore, community education on the ecosystem services provided by wetlands is required especially when South Africa has been classified as water scarce country. Additionally, it is critical to educate communities on the health implications of wetland pollution. These are critical recommendations because wetlands in the study area are located close to residential areas and are therefore easily accessible for environmental crimes. Furthermore, there is need for massive wetland rehabilitation programs in the study area because construction waste is voluminous and heavy, and therefore cannot be eroded easily. This means that with repeated deposition, wetlands will eventually disappear. Finally, there is need for a multistakeholder environmental management approach where NGOs, local municipalities, private companies, local communities among others collaborate. This is a critical approach to governance because involves sharing of resources, information and skills required to achieve environmental sustainability. Ultimately, the recommendations are critical because they lead to restoration of critical ecosystems in a water scarce country like South Africa.

# CHAPTER FIVE

# ANALYSIS AND DISCUSSION OF FINDINGS

**Overview of the chapter**

This chapter provides an amalgamated discussion of the findings of this study. The significance of this chapter is that it brings into focus all the issues raised in previous chapters (based on the publications), with a view to establish interrelationships and causal links between issues raised or observed in this study. This is an important part of the study, because it helps to establish a basis for the formulation of potential solutions to achieve environmental sustainability in construction and wetland conservation.

The chapter begins with a discussion of the factors affecting sustainable management of CDW in the context of SSA, with greater emphasis on South Africa. Next, the chapter presents a discussion of the current methodological approaches to the management of CDW in South Africa, in order to identify the weaknesses associated with them, and ultimately, to propose possible solutions. Then, the chapter proceeds to discuss the effects of CDW disposal on wetland ecosystems in the Gauteng Province of South Africa (specifically Diepsloot and Tembisa townships).

It is established through the key discussion points in this chapter that there is a direct correlation between barriers to CDW management in South Africa, with methods currently deployed to manage the waste stream. The limited efficacy of these methods is also directly linked to the phenomenon of dumping in wetlands in the study area. Ultimately, the dumping leads to massive loss of wetlands, as illustrated in previous chapters.

### 5.1. Construction and demolition management barriers in sub-Saharan Africa.

The construction sector in SSA has grown significantly in recent decades, and this is due to several reasons, including population growth and economic expansion (Fitchett & Rambuwani, 2022). However, while economic growth is the goal of every country, expansion of the construction sector leads to massive generation of CDW, especially in the absence of lean building strategies (see Fitchett & Rambuwani, 2022). This is the case in SSA countries like South Africa, where local urban authorities are struggling to cope with the massive volumes of CDW generated in the last two decades. It was found that the South African construction sector has generated approximately 5 to 8 million tons of CDW per annum for the last twenty years (Bester et al., 2017; DEA, 2018). On further investigation, this estimation is probably far from accurate, because both the population in South Africa, and by extension, the construction sector, have grown significantly in the last twenty years, meaning that the production of CDW has also expanded. This is supported by the fact that even the South African government acknowledges the problem of poor solid waste data reporting or collection in the country (DEA, 2018).

From the synopsis of literature presented in Chapter 1, it was observed that sustainable CDW management is vigorously reliant on the presence of strong and efficient institutions that can provide a balance between achieving urban growth and maintaining environmental sustainability. According to Ostrom (2005), institutions are guided by both formal and informal rules, where formal rules are directed by legal structures and informal rules are ethical in nature. Therefore, since rules can be both legal or implicit, strong institutions in waste management are guided by environmental ethics in a way that balances with economic growth. Yet, the literature discussed in this study suggests that the SSA region lacks strong institutions to achieve this (e.g. Godfrey & Nahman, 2007; Laubscher, 2012). For instance, SSA countries such as South Africa have weak local institutions that are characterized by an incessant lack of capacity and competent human resources to implement city processes such as sustainable waste management (e.g. Godfrey & Nahman, 2007; Ferronato & Toretta, 2019). This problem emanates from systemic corruption in recruitment processes and financial governance leading to inefficient and unethical handling of city processes (see

Godfrey & Nahman, 2007; Laubscher, 2012; Godfrey et al., 2019), such as CDW management. From the absence of such strong and ethical institutions, it is clear and obvious that service delivery suffers severely.

In addition, weak institutions in SSA countries like South Africa manifest in the form of the lack of capacity for municipalities to transition to sustainable global initiatives such as the closed loop system and its three principles of 'reduce', 'recycle' and 'reuse' CDW. A closed loop system provides significant environmental and economic benefits for a given economy. For example, the practice of circular economy systems in construction is well-entrenched in city governance systems in developed countries, especially those in Europe, where recycling rates top 70% (e.g. Wahlström et al., 2020). This reduces the volumes of CDW, and the need for extraction of fresh aggregates from the environment, thereby working towards the achievement of sustainability in construction.

Furthermore, it is important to note that the success of closed loop systems in developed countries is reliant on strong and coherent institutional systems which are supported by dedicated legislation or policies (e.g. the Waste Framework Directive of 2008). In developed countries, success of closed loop systems in construction is linked to the presence of relevant technologies and competent personnel to operate the associated machinery. When analysed closely, the presence of relevant technology and personnel is heavily linked to strong institutions that are service delivery oriented. In an ethical and functional set up like this, local authorities provide the necessary materials and human resources to achieve their constitutional mandates. In contrast, SSA countries like South Africa lag significantly in this regard due to multifaceted issues. This means that globally accepted sustainability vehicles such as closed loop systems are hard to achieve in South Africa. The problems with achieving sustainability in construction in South Africa are therefore clearly linked to institutional failure.

It is observed in this study that institutional problems are not limited to local municipalities, but also extend to national level. It is clear, when municipal financing systems are brought into focus, centralization of financial systems is widespread (e.g. Erk, 2014; COSATU, 2023). As mentioned in Chapter 1, centralized political systems are typified by control of major governance processes at the national level where bureaucracy is ever present (see Erk, 2014; Worrall et al., 2017; COSATU, 2023). In South Africa, bureaucracy and interparty political machinations often lead to disbursement of municipal funds only at the end of a fiscal year (Laubscher, 2012; Worrall et al., 2017; COSATU, 2023). This has major service delivery ramifications which affect sustainability-related initiatives, such as CDW management, in South Africa's major cities. Therefore, it is not an exaggeration to argue that centralization of power at the national level also affects city-level processes.

Poor institutional systems at national level also manifest through a lack of dedicated waste policy in SSA countries like South Africa. The lack of policy dedicated to construction waste is a serious institutional weakness, and a barrier to sustainable CDW, because construction processes generate the largest amount of waste globally. While in developed countries such as in Europe they have policies like the 'Construction and demolition waste management protocol', SSA countries depend on generic policies and laws such as the National Environmental Management: Waste Act 59 of 2008, and the National Environmental Management: Waste Amendment Act of 2014. These legal instruments generically describe how solid and liquid waste, inert and non-inert waste should be governed in South Africa. While these legislations provide a basis for waste management in South Africa, this study argues that this is only 'representational' in nature. This is because the two Waste Acts are generic, and do not explain how to manage non-toxic waste like CDW, which is casually designated as 'general waste' based on the view that it does not pose an immediate threat to the environment.

It is argued that this conceptualization of inert CDW emanates from a humanist view of the world, where the interests of humanity go beyond nature and other entities (see Rusen, 2006). What is directly linkable to local institutions is that these legal instruments influence the formation of by-laws, which also classify inert CDW as general waste based on its lack of toxins. The classification of some waste streams as hazardous and immediately risky to the environment is based on the presence of toxic chemicals within them. For example, disposal of asbestos in riverine environments leads to migration of silicon, which is harmful to water quality and aquatic life (e.g. Erba & Cantoni, 2019). Yet, when asbestos material is still attached to a building, it presents gradual damage to the environment and/ or human health

(USDHHS, 2014). This analogy can be successfully applied to inert CDW, which can be immediately dangerous to ecosystems such as wetlands through massive sedimentation, not toxicity. Yet, when placed in a landfill, CDW only leads to rapid consumption of space, which is considered as a gradual environmental threat. In this perspective, sustainable management of CDW in SSA countries such as South Africa is impeded by the nature of the waste law, which fails to recognize issues of waste temporality in relation to pollution.

### 5.2. Methodological Imperatives for Construction and Demolition Waste in South Africa

The methods and approaches currently deployed in the management of CDW in South Africa are inextricably linked to the institutional failures discussed in the previous section. It is argued that weak institutions, characterized by corruption, poor financing, and other problems, pave the way for many unsustainable ways of handling waste. The emergence of unsustainable ways of handling waste in South Africa suggests the involvement of multiple actors in the handling process. As the findings of this study suggest, CDW management in South Africa involves environmental NGOs, municipalities, construction companies and their third-party contractors. As a result of institutional failure, the first two organizations are typically involved in environmental remediation while the latter two are generally involved in unsustainable waste handling activities such as illegal dumping, and this is an obvious indication of a breakdown in municipal systems such as law enforcement. It is argued that weak institutional performance motivates CDW management methods such as illegal dumping or infilling of wetlands in some parts of major cities to make space usable for illicit construction as argued in previous chapters. Environmental crimes of this nature are committed by some unscrupulous construction companies and their sub-contractors due to poor laws and weak enforcement, among other reasons.

From this study, it was found that the methods currently deployed in CDW management in South Africa can be classified as 'sustainable' or 'unsustainable'. According to the data set informing this study, landfilling, remediation, and occasional recycling are some of the methods that can be classified as sustainable because of their perceived environmental benefits. However, when investigated further, landfilling of inert waste does not suggest a method that is sustainable because CDW rapidly consumes landfill space due to its physical attributes, particularly in the absence of closed loop methods. Placed in the context of existing literature in South Africa, some landfill sites that used to permit the disposal of CDW in Johannesburg have been closed off due to full capacity (Simelane, 2017). On the other hand, even though recycling exists in South African major cities like Johannesburg, it is hindered by the lack of maintenance of the associated machinery, which results in a total halt to closed loop systems. Thus, while recycling is an environmentally sustainable initiative, in the presence of weak institutional systems such as in Johannesburg, its success is not guaranteed. Additionally, although remediation conducted by NGOs and municipalities moves waste from places of illegal disposal to municipally permitted spaces such landfill sites, it only represents a change in location, and removal from public spectacle. In addition to this, remediation is financially unsustainable, and this could explain why illegal disposal sites are proliferating in major cities like Johannesburg.

### 5.3. Effects of CDW on wetland ecosystems

The discussion points to the fact that CDW management methods used in South Africa leads to massive environmental degradation. Methods such as illegal dumping typically affect wetland ecosystems, which are targeted for illegal dumping to evade landfill disposal fees or infilling to create dry land for illegal construction. From the field observations, which are supported by pictorial evidence throughout this study, inert CDW is typically the object of illegal disposal in affected wetlands. When using the logic of South African waste law, inert CDW does not pose an immediate threat to the environment. Yet, from the findings of this study, it is suggested that this position is not adequately informed by scientific facts. This investigation found that inert CDW immediately impedes the ability of wetlands to perform their functions such as water filtration, flood attenuation, provision of habitat and fresh water to various species, carbon capture, and river recharge among others, and this is supported by an existing study in the studies area (see Mangoro & Kubanza, 2023). This study illustrated that wetlands in the research area suffered massive sedimentation in the last 20 years due illegal dumping of CDW for various reasons. A predictive study based on dumping trends in the last 20 years suggests that by 2040, wetlands in the study area will almost disappear, which attests to the ability of inert CDW to cause massive environmental deterioration. It is argued that the environmental performance of CDW should also be determined based on the location of disposal and not through toxicity as enshrined in South African waste law. Therefore, it is obvious from this argument that South Africa needs a revision of current waste laws, or the formation of new ones, to cater to specific waste streams and their potential to disrupt the environment.

### 5.4. Solutions for sustainable CDW management in South Africa

In light of the challenges faced in CDW management in the study areas, and South Africa at large, this study has suggested that a blend of the two waste management concepts of circular economy and industrial ecology can be effective. The practical aspects of this solution involve the establishment of an online platform/ database of construction and demolition sites in Gauteng or South Africa at large. On this platform, all types of waste generated at construction sites and their precise location can be recorded. CDW produced at these sites can be used at other construction sites and minimise extraction of raw materials from the environment. In this proposed method, unused cementitious CDW can be used to manufacture new construction materials such as bricks or paving blocks. This can be achieved by crushing cementitious CDW and mix with crushed plastic waste sourced from other industries in the true tradition of industrial ecology. Implementation of this method, together with stringent CDW legislation can effectively reduce pressure on the environment, particularly through illegal dumping and extraction of raw materials. It can therefore be observed that a blend of circular economy and industrial ecology can be profitable in the management of CDW.

### 5.5. Conclusion

This study investigated several issues concerning construction and demolition waste management in Johannesburg and Ekurhuleni. It is clear from the findings that CDW presents many urban environmental challenges that arise from political and administrative deficiencies. These problems lead to major environmental sustainability challenges in the absence of tailor-made solutions for cities in developing countries like South Africa. This study has recommended a major solution which requires a blend of circular economy and industrial ecology to effectively manage CDW in SSA. The study proposes that for effective use of the proposed hybrid method of CDW management in South Africa, an online platform uniting all the relevant stakeholders must be developed by City of Johannesburg Municipality and City of Ekurhuleni Municipality for the sharing of critical information about construction waste. To eliminate these problems, several suggestions are presented in Chapter 6.

# CHAPTER 6

# GENERAL CONCLUSION AND RECOMMENDATIONS

**Overview of the chapter**

This chapter is composed of a summary of the key findings of this study, and it also provides recommendations for future studies on CDW management in South Africa. The significance of this chapter is that it summarizes the main findings of the thesis and provides links to the overall goals of the study. As highlighted in Chapter 1, the general aim of this study was to investigate CDW management processes in SSA, using South Africa as a case study, in order to understand how this affects wetland ecosystems. The specific objectives of the study were to create an inventory of the challenges or barriers to sustainable CDW management in South Africa. The other objective of the study was to determine the impacts of CDW on the functionality of selected wetland ecosystems in Diepsloot and Tembisa (City of Johannesburg and City of Ekurhuleni Municipality). Furthermore, the study aimed at proposing a suitable methodological approach to sustainably manage CDW in SSA, using South Africa as a case study. The final objective of the study was to propose ways in which stakeholders in construction can collaborate to effectively manage CDW to achieve environmental sustainability.

The aim of the study emerged from a gap in extant literature and empirical observations in the study areas in the last 5 years in the Gauteng Province. An online article by Gekco (2018) states that suburban CDW was rapidly filling wetlands in Diepsloot and surrounding areas. However, there has been no notable academic study to investigate this growing environmental problem in the Gauteng Province and South Africa at large. Therefore, the aim and objectives of this study were centred on proposing methods for sustainable management of CDW as a strategy to reduce or eliminate dumping in wetlands.

## 6.1. Key Findings

Using a hybrid research approach of semi-structured interviews, existing literature, and GIS and remote sensing techniques, this study has demonstrated that CDW is a major urban environmental problem in South African cities. This arises from several significant challenges that can be traced to institutional failure, for example, shortage of landfill space and technologies required to achieve circularity in construction, and poor law enforcement among other challenges. Although the study found several significant barriers to sustainable CDW management in Johannesburg and Ekurhuleni, it is argued that a shortage of landfills, accompanied by exorbitant landfill disposal fees are largely responsible for the widespread illegal dumping in wetlands across the study areas. To reduce or eliminate this problem, it is argued that a collaborative strategy involving stakeholders such as municipalities, non-governmental organizations, construction companies, and law enforcement agents among others, should be established. It is additionally argued that a collaboration of these stakeholders should be based on an online-based information system where data sharing is the primary focus. This collaboration would focus on generating ideas on how to rehabilitate wetlands in the study areas. For example, physical removal of waste from the affected wetlands using both mechanical systems and direct human labour. In addition, it would be crucial to delineate and buffer the wetland in the area and establish a roster in which community member are designated as custodians to avoid repeated dumping.

Another major finding of this study is that CDW poses significant threats to the overall functionality, and ultimately the existence of wetland ecosystems. It is argued that although CDW is generally regarded as inert (chemically inactive) and therefore constitutes 'general waste' which does not pose immediate threat to the environment (NEMA no: 59 of 2008), this is not always the case. This study finds that inert CDW can cause an immediate threat to the environment depending on the location of disposal. Due to its massive volumes, CDW disposal results in massive sedimentation that disrupts the ability of wetlands to provide ecosystem services such as flood attenuation, water filtration, carbon sequestration, and habitat provision, among other functions. As a result, disruption of wetland function can lead to floods, habitat loss, and loss of life, among other negative outcomes. Ultimately, this study argues that the conceptualization or classification of waste cannot be based only through the lens of toxicity and its ability to cause harm, but also on its physical characteristics.

Another major finding of the study is that there is need for a change in the methodological approaches to CDW management in South Africa. It is argued that the current methods deployed in the management of CDW, including disposal in landfills, illegal dumping, and reactive remediation among other ways, are environmentally unsustainable. Therefore, it is argued that an amalgamation of two kindred concepts of 'circular economy' and 'industrial ecology' can offer a sustainable strategy to CDW management in South Africa. Through this hybrid methodology, it is proposed that plastic waste from industries outside of construction can be used together with crushed cementitious CDW to manufacture eco-bricks that can be used in making paving material. This strategy has been used successfully in countries like Singapore through a company called 'ReBricks[6]' and massive volumes of plastic waste and CDW have been reclaimed into material of capital value. In addition to this, this hybrid method also incorporates licensed waste pickers to reclaim reusable waste such as bricks, and so reduce the amount of material termed as 'waste'. Finally, the success of this hybrid method requires municipal or private sector investment in recycling machinery to significantly reduce CDW.

It is ultimately argued that the factors affecting environmental sustainability in the construction sector emerges largely from institutional failures. It is found that municipalities in South Africa are unable to effectively deliver their constitutional mandate to ensure a clean and healthy environment as a result of administrative and financial misappropriation. However, it must be noted that institutional failure is a problem that is also applicable to construction companies that lack systems and strategies to ensure sustainable handling of CDW.

[6] www.rebricks.id

### 6.2. Recommendation for improvement of CDW management in South Africa

Although studies related to waste management has gained considerable attention in the last decade in South Africa, not much has been done to investigate how best to achieve sustainable CDW management in the country. For example, although there is mention of the environmental benefits of the transition to a circular economy, very little has been done to investigate how best to achieve circularity in construction, especially considering the political and economic landscape in South Africa. This study has proposed a hybrid approach which amalgamates facets of 'circular economy' and 'industrial ecology' which if implemented can produce significant environmental benefits.

Construction processes are typically preceded by full or partial demolition of existing structures to generate land for new buildings. Many buildings in the Gauteng province, particularly in the City of Johannesburg have become structurally impaired or unfit for modern use. This has led to numerous cases of demolition around the city, which causes massive and rapid generation of CDW. Similarly, construction of new buildings, particularly involving mega structures can be observed in both the City of Johannesburg and City of Ekurhuleni. The construction processes also generate massive volumes of CDW in the absence of measures to reduce waste. As this study has found, there is rampant illegal dumping of CDW in both the City of Johannesburg and the City of Ekurhuleni, especially in wetlands close to informal settlements. From this state affairs, it is clear that critical solutions can be developed to sustainably manage CDW by establishing relevant collaborations between actors involved in the generation of CDW (constructors and demolishers).

To sustainably manage CDW through a collaboration between waste producers, there is a critical need for establishment of an online platform that registers all construction sites in the study areas, although this strategy can be adopted on a bigger scale. This platform is critical for documenting the magnitude of construction or demolition sites, and the quality, types and/or volume of CDW generated. Depending on these characteristics, CDW at one site can be used at another building project, and minimise waste to landfill, or waste to wetlands.

Additionally, CDW producers can collaborate through planned educational workshops on waste management. Among other ways, educational workshops can be conducted on how to minimise waste before, during and after the construction or demolition phase. For example, the commonly used method of demolition in South Africa is the razing down of structures without consideration for reuse of materials. This emerges from the lack of training on how to sustainably manage construction phase during all construction phases. On the basis of this, it is crucial to establish educational workshops for personnel in construction and demolition of buildings on how to sustainably manage CDW.

In addition, the Construction Board of South Africa can introduce mandatory certification for construction workers on circular economy as basic requirement for employment. Considering the economic condition in South Africa at large, it is necessary to make the certification either free or affordable for the target groups. It is crucial to note that most general workers at construction sites generally hold limited to no educational qualifications which significantly diminish their economic prospects. Therefore, it can be a prudent idea to offer the certification for free or at low cost to attract the target market, and to reduce illicit recruitment for construction projects in the study areas, and South Africa at large. The Construction Board unites all personnel in the sector, and its resolutions establish direction of operations in the sector.

It is however important to note that the challenges faced in CDW management in South Africa cannot entirely be ascribed to the construction industry alone. As the study has shown, sustainable CDW management in South Africa is hindered by strong institutional problems such as alleged corruption, poor recruitment practices, poor policing and lack of funding. To reduce these problems, the first step can include a human resources audit where all employees can be assessed against their primary roles. This is critical since local municipalities are often criticised for alleged corrupt hiring practices. This process can be used to eliminate unqualified or incompetent officials, leading to the establishment of an effective workforce. In terms of the limited funding, with an effective workforce, it is possible to search for funding from public and private organisations to improve CDW management processes. Additionally, with this workforce, the funds can be effectively used to manage CDW, such as the purchase of machinery (crushers, skips, trucks e.t.c). Regarding the poor policing, this is also linked to an effective workforce. This means that with a competent workforce, effective collaborations with municipal and state police can be made, leading to effective law enforcement. In light of this, it is possible to achieve sustainable CDW management in South Africa. It is important to note that the success of institutions and their activities is premised on a competent workforce.

### 6.3. Recommendation for future studies

Although this study has recommended several ways to sustainably manage CDW in the study areas and South Africa at large, more is required to achieve the desired environmental goals. Therefore, several studies are still required to investigate the current construction processes and how to sustainably manage CDW. This study has revealed that there is limited knowledge on the environmental effects of CDW in South Africa. The existing studies tend to peripherally mention how poor construction waste management can lead to massive environmental deterioration. However, such studies offer very little to the understanding of the environmental effects of CDW management in the context of South Africa and SSA at large. Based on this, it is recommended that more research must be done to investigate and quantify the environmental impacts of CDW on both terrestrial and marine environments. Studies of this nature are crucial because they enhance human understanding of the environmental performance of materials, which is very important in the formation or strengthening of policy. This study posits that the classification of non-toxic CDW as general waste which poses little threat to the environment is not based on empirical studies.

Further to the above, it is argued that future studies on ways to protect wetlands is very important in the context of South Africa. If the current intensity of illegal dumping in wetlands continues in the next twenty years, wetland loss is going to continue. This is a major environmental problem which affects both humanity and the environment. For humanity, it must be noted that South Africa is classified as a water-scarce country, and therefore, wetlands are crucial in the supply of water, while for the environment, loss of wetlands leads to loss of habitat, and loss of the ability to attenuate floods among many other functions. On this basis, it is argued that there is need for studies on how to protect wetland ecosystems in low-income areas where much of the illegal dumping occurs. It is recommended that wetlands in the study area need robust rehabilitation programs to restore their integrity. This is crucial because the area is prone to floods that are partly facilitated by the poor state of wetlands in the area. Apart from the rehabilitation, there is need for the wetlands to be buffered and be protected as areas of local tourism.

Finally, there is a need for studies that investigate environmental crimes in construction at the national level. In Chapters 2 and 3, it was observed that CDW transportation to landfills involves either construction companies or their sub-contractors. It was also discovered that despite claims by some construction companies that they demand accountability from their sub-contractors, illegal dumping is fast-growing as evidenced by the immense presence of illegally dumped CDW across the City of Johannesburg and City of Ekurhuleni. Studies that follow the movement of CDW from the point of generation to the point of disposal are therefore required. Such studies are crucial in the attempts to eliminate environmental crimes related to the construction sector.

## References


Abad-Segura, E., de la Fuente, A. B., Gonzalez-Zamar, M.D. & Belmonte-Urena, L.J. (2020). Effects of the Circular Economy Policies on the Environment and Sustainable Growth: Worldwide Studies. *Sustainability*, Vol. 12, No. 14, 5797, doi.10.3390/su12145792

Abbas Z, Yang G, Zhong, Y &Zhao Y. (2021). Spatiotemporal change analysis and future scenario of lulc using the CA-ANN approach: A case study of the greater bay area, China. *Land*. Vol. 10, No. 6, p. 584, https://doi.org/10.3390/land10060584

Aboginije, A., Aigbavboa, C., & Thwala, W. (2020). Determining the Impact of Construction and Demolition Waste Reduction practices on Green Building Projects in Gauteng Province, South Africa. Proceedings of the International Conference on Industrial Engineering and Operations Management Dubai, UAE, March 10-12.

Adeeyo, A.O., Ndlovu, S.S., Ngwagwe, L.M., Mudau, M., Alabi, M.A., & Edokpayi, J.N. (2022). Wetland Resources in South Africa: Threats and Metadata Study. *Resources*, Vol. 11, No. 6, p. 54, https://doi.org/10.3390/resources11060054

Agamuthu, P. (2008). Challenges in sustainable management of construction and demolition waste. *Waste Management and Studies*, Vol. 26, No.6, p.491–492, doi: 10.1177/0734242X08100096.

Agbede, T.M., Oyewumi, A., Adekiya, A.O., Adebiyi, O.T.V., Abisuwa, T.A., Ijigbade, J.O., Ogundipe, C.T., Oladele, S.O., Olaogun, O., & Eifediyi, E.K. (2022). Assessing the synergistic impacts of poultry manure and biochar on nutrient-depleted sand and sandy loam soil properties and sweet potato growth and yield. *Experimental Agriculture*, Vol. 58, No. 54, p. 1–21, https://doi.org/10.1017/S0014479722000497

Agbesola, Y. (2013). Sustainability of Municipal Solid Waste Management in Nigeria: A Case Study of Lagos, Master of Science dissertation, Linkoping University.

AgriOrbit. (2020). Invasive alien plants and their impact on wetlands. Invasive alien plants and their impact on wetlands – AgriOrbit (Accessed on 23/11/2023).

Ahidur, R. (2016). Impact of Human Activities on Wetland: A Case Study from Bongaigaon District, Assam, Indian. *International Journal of Current Microbiology and Applied Sciences*, Vol. 5, No. 3, p.392–396, http://dx.doi.org/10.20546/ijcmas.2016.503.046

Ahmad, M., Zhao, Z. and Li, h. (2019). Revealing stylized empirical interactions among construction sector, urbanization, energy consumption, economic growth and CO2 emissions in China. *Science of the Total Environment*, Vol, 657, p.1085–1098. https://doi.org/10.1016/j.scitotenv.2018.12.112

Ajayi, O.M., Koleoso, H.A., Soyingbe, A.A., & Oladiran, O.J. (2008). 'The practice of waste management in construction sites in Lagos State; Nigeria', The Construction and Building Studies Conference of the Royal Institution of Chartered Surveyors, Dublin Institute of Technology, 4–5 September 2008.

Akhtar, A. & Sarmah, A.K. (2018). 'Construction and demolition waste generation and properties of recycled aggregate concrete: a global perspective', *Journal of Cleaner Production*, Vol. 186, p.262–281, http://dx.doi.org/10.1016/j.jclepro.2018.03.085

Al-Fares, W. (2013). Historical Land Use/Land Cover Classification Using Remote Sensing, Springer Briefs in Geography. Springer International Publishing, Heidelberg. doi.org/10.1007/978-3-319-00624-6

Ali, T.H., Akhund, M.A., Memon, N.A., Khahro, S.H., & Imad, H.U. (2019). Application of artificial intelligence in construction waste management: a conceptual framework for effective waste management system. Paper presented at the 8th International Conference on Industrial Technology and Management, Cambridge, UK, doi: 10.1109/ICITM.2019.8710680.

Ali-Khani, S., Nummi, G. and Ojala, A. (2023). Modified, Ecologically Destructed, and Disappeared – History of Urban Wetlands in Helsinki Metropolitan Area. *Wetlands*, Vol. 43. No. 33, p. 2–24, doi.org/10.1007/s13157-023-01671-w

Almusawi, M.B.H., Karim, A.T.B.A., & Ethaib, S. (2022). Evaluation of Construction and Demolition Waste Management in Kuwait. *Recycling*, Vol, 7, No, 6, p.88, doi.org/10.3390/recycling7060088

Al-Otaibi, A., Bowan, P.A., Abdel daiem, M.M., Said, N., Ebohon, J.O., Alabdullatief, A., Al-Enazi, E., & Watts, G. (2022). Identifying the barriers to sustainable management of construction and demolition waste in developed and developing countries. *Sustainability*, Vol. 14, 7532, https://doi.org/10.3390/ su1413753.

Nelles, M., Grunes, J., & Morscheck, G. (2016). Waste Management in Germany – Development to a Sustainable Circular Economy. *Procedia Environmental Sciences*, Vol. 35, p.6–14, doi: 10.1016/j.proenv.2016.07.001 p

Alotaibi, A., Edum-Fotwe, F., & Price, A.D.F. (2019). 'Critical barriers to social responsibility implementation within mega-construction projects: the case of the Kingdom of Saudi Arabia', *Sustainability*, Vol. 11, No. 6, pp.1755, https://doi.org/10.3390/su11061755.

Ametepey, O., Aigbavboa, C., & Ansahm, K. (2015). 'Barriers to successful implementation of sustainable construction in the Ghanaian construction industry', *Procedia Manufacturing*, Vol. 3, p.1682–1689, doi: 10.1016/j.promfg.2015.07.988.

Ametepey, S.O. & Ansah, S.K. (2014). Impacts of Construction Activities on The Environment: The Case of Ghana. *Journal of Environment and Earth Science*, Vol. 4, No. 1. p.934–948.

Atkinson, D. (2003). 'Post-apartheid local government reforms: a small-town perspective', Occasional Papers Reflecting Continuing Studies Produced for the Centre for Development and Enterprise, CDE FOCUS, Vol. 8, p.1–11.

Ampofo-Anti, N. (2009). Green Building Handbook for South Africa Chapter: The environmental impacts of construction materials use: a life cycle perspective. https://studiesspace.csir.co.za/dspace/bitstream/handle/10204/3386/Ampofo-Anti_2009.pdf?sequence=1&isAllowed=y (Accessed on 30/01/2024).

Assche, K.V. & Gruezmacher, M. (2023). Remembering Ypres. Post- War Reconstruction, Land and the Legacies of Shock and Conflict. *Land,* Vol. 12, No. 1, p.21, doi.org/ 10.3390/land12010021.

Atta, I. & Bakhoum, E.S. (2023). Environmental feasibility of recycling construction and demolition waste. *International Journal of Environmental Science and Technology*, Vol. 21, p.2675-2694, doi.org/10.1007/s13762-023-05036-y

Bagdi, N., Aggarwal, V. & Sherwal, N. (2013). Management of construction waste in India: a case of green technology. *Global Journal of Management and Business Studies*, Vol. 3, No. 4, p.361–364.

Balayannis, A. (2018). Following pesticides in disposal: a Chemical Geography. PhD Thesis. University of Melbourne. Australia.

Ballut-Dajud, G.A., Herazo, L.C.S., Fernandez-Lambert, G., Marin-Muziz, J.L., Mendez, M.C.L., & Betanzo-Torres, E.A. (2022). Factors Affecting Wetland Loss: A Review. *Land*, Vol. 11, No. 3, p.434, https://doi.org/10.3390/land11030434

Bega, S. (2018). Suburban rubble fills Diepsloot. https://gekco.co.za/suburban-rubble-fills-diepsloot/ (Accessed on 14/12/2023).

Bertino, G., Kisser, J., Zeilinger, J., Langergraber, G., Fischer, T., & Osterreicher, D. (2021). 'Fundamentals of building deconstruction as a circular economy strategy for the reuse of construction materials', *Applied Sciences*, Vol. 11, No.3, p.939, doi: 10.3390/app11030939.

Bester, J., Kruger, D., & Miller, B. (2017). 'South African construction and demolition waste procedure and its sourced material effects on concrete', Matec Web of Conferences, Vol. 120, 02008.

Bewiadzi, S., Awubomu, R., & Glover, N. (2019). Searching and Cracking: Stone Quarrying, Livelihood and the Environment in the Daglama Quarry Site in the Ho Municipality. *West African Journal of Applied Ecology*, Vol. 26. p.149–166.

Bhagyanathan, A., & Dhayanithy, D. (2023). A Canal, Urban Sprawl and Wetland Loss: The Case of Kozhikode, India, From Colonialism to Climate Change Era. *Area*, Vol. 55, p.435–446. doi:10.1111/area.12875

Bogoviku, L., & Waldmann, D. (2021). Modeling of mineral construction and demolition waste dynamics through a combination of geospatial and image analysis. *Journal of Environmental Management*, Vol. 282, 111879, doi.org/10.1016/j.jenvman.2020.111879

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Studies in Sport, Exercise and Health*. Vol, 11, No. 4, p. 589–597.

Canty, M.J. (2014). Image analysis, classification and change detection in remote sensing: with algorithms for ENVI/IDL and Python, Third edition. ed. CRC Press, Boca Raton

Cárcel-Carrasco, J., Peñalvo-López, E., Pascual Guillamón, M., &d Salas-Vicente, F. (2021). 'An overview about the current situation on C&D waste management in Italy: achievements and challenges'. *Buildings*, Vol. 11, No. 284, doi: 10.3390/buildings11070284.

Castell-Rüdenhausen, M., Wahlstrom, M., Astrup, T.F., Jensen, C., Oberender, A., Johansson, P., & Waerner, E.R. (2021). Policies as Drivers for Circular Economy in the Construction Sector in the Nordics. *Sustainability*, Vol. 13, p.9350, https://doi.org/10.3390/su13169350

Chamberlain, K., Storey, B., Brown, J., Rayburg, S., Rodwell, J., & Neave, M. (2022). Cleaning up Forever Chemicals in Construction: Informing Industry Change. *Sustainability*, Vol. 14, p.2854. https://doi.org/10.3390/su14052854

Chamberlain, L.A., Aguayo, T., Zerega, N.J.C., Dybzinski, R., & Egerton-Warburton, L.M. (2022). Rapid improvement in soil health following the conversion of abandoned farm fields to annual or perennial agroecosystems. *Frontiers in Sustainable Food Systems*, Vol. 6, p.1010298, https://doi.org/10.3389/fsufs.2022.1010298

Chu, E.W. & Karr, J.R. (2017). Environmental Impact: Concept, Consequences, Measurement. Reference Module in Life Sciences, https://doi.org/10.1016%2FB978-0-12-809633-8.02380-3

COSATU - Congress of South African Trade Unions. (2023). SAMWU Concerned by Several Municipalities' Failure to pay May salaries on Time, Demands Immediate Payment of Salaries, COSATU. http://mediadon.co.za/ (accessed 30 August 2023).

Coni, D. & Madhi, A. (2021). The Albania Earthquake of 2019: Causes of Damage to the Buildings and Its Social Consequences. *Civil Engineering and Architecture*, Vol, 9 No, 7, p. 2381-2388, DOI: 10.13189/cea.2021.090724

Couto, A. & Couto, J.P. (2010). 'Guidelines to improve construction and demolition waste management in Portugal', in Pomffyova, M (Ed.): *Process Management*, Intech Publishers, Slovakia.

Mangoro, N., Kubanza, N.S., & Simatele, M.D. (2023). An assessment of literature on construction and demolition waste management barriers in Sub-Saharan Africa: lessons and implications for sustainability in South Africa. International Journal of Environment and Waste Management,doi: 10.1504/IJEWM.2023.10060718

Cowardin, L. M., Carte, V., Golet, F., & LaRoe, E. T. (1979). Classification of Wetlands and DeepWater Habitats of the United States. US: Interior Fish and Wildlife Service Office of Biological Services. https://www.epa.gov/sites/default/files/2017-05/documents/cowardin_1979.pdf (Accessed on 23/08/2023).

Dainty, A.R.F. & Brooke, R.J. (2004). 'Towards improved construction waste minimisation: a need for improved supply chain integration?' *Structural Survey*, Vol. 22, No. 1, p.20–29, doi: 10.1108/02630800410533285.

Dangi, M.B., Schoenberger, E., & Boland, J.J. (2017). 'Assessment of environmental policy implementation in solid waste management in Kathmandu, Nepal', *Waste Management and Studies,* Vol. 35, No. 6, p.618–626, https://doi.org/10.1177/0734242X17699683

Dantata, N., Touran, A., & Wang, J. (2005). 'An analysis of cost and duration for deconstruction and demolition of residential buildings in Massachusetts', *Resources, Conservation and Recycling,* Vol. 44, p.1–15, doi: 10.1016/j.resconrec.2004.09.001.

Davidson, N.C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Studies*, Vol. 65, No.10, p.936-941, http://dx.doi.org/10.1071/MF14173

De Oliveira, M.C.V., Klafke, R., & Chaerki, S.F. (2022). 'The challenge of urban solid waste management in Brazil', *Economia, Sociedad y Territorio*, Vol. 32, No. 68, p.177–206, http://dx.doi.org/10.22136/est20221738

DeBlonde, T. & Hartemann, P. (2013). Environmental impact of medical prescriptions: assessing the risks and hazards of persistence, bioaccumulation and toxicity of pharmaceuticals. *Public Health*, Vol. 127, No. 4, p.312-31, https://doi.org/10.1016/j.puhe.2013.01.026

Debnathi, S., Dash, R.R., Dutta, R.K., & Dash, R.R. (2009). Effect of Construction and Demolition Waste on Properties of Soil. Proceedings of the Civil Engineering Conference – Innovation Without Limits (CEC-09). 18 – 19 September.

Debrah, J.K., Teye, G.K., & Dinis, M.A.P. (2022). 'Barriers and challenges to waste management hindering the circular economy in Sub-Saharan Africa'. *Urban Science*, Vol. 6, No. 3, p.57, https://doi.org/10.3390/ urbansci603005.

Den Hond, F. (2000). Industrial Ecology: A Review. *Regional Environmental Change*, Vol. 1, No. 2, p. 60 – 69, doi: 10.1007/PL00011534

Dibs, H., Ali, A.H., Al-Ansari, N., & Abed, A.A. (2023). Fusion Landsat-8 Thermal TIRS and OLI Datasets for Superior Monitoring and Change Detection using Remote Sensing. *Emerging Science Journal*, Vol. 7, No. 2, http://dx.doi.org/10.28991/ESJ-2023-07-02-09

Diotti, A., Galvin, A.P., Piccinali, A., Plizzari., & G., Sorlini, S. (2020). Chemical and leaching behavior of construction and demolition wastes and recycled aggregates*. Sustainability*, Vol. 12, 10326, doi:10.3390/su122410326

Dountchev, A., Dimova, D., & Dimitrov, M. (2017). Riparian Forests: Benefits, Present Condition, Conservation. WWF-Bulgaria, https://www.wwfmmi.org/?8540966/riparian-forests (Accessed on 27/08/2023).

Earth5R. (2023). The Growing Menace of Construction Dust Pollution in India: Causes, Impacts, And Solutions. Accessed from earth5r.org/ (Accessed on 14/07/2023).

Ehrenfeld, J.G. (2000). Evaluating Wetlands within an Urban Context. *Ecological Engineering,* Vol.15, No.3, p.253-265. http://dx.doi.org/10.1016/S0925-8574(00)00080-X

Ekurhuleni Metropolitan Municipality. (2008). Biodiversity Report. Local Action for Biodiversity. https://www.ekurhuleni.gov.za/wp-content/uploads/2022/05/env_biodiversity_report_2008.pdf (Accessed on 15/08/2023)

El-Shaboury, N. & Marzouk, M. (2019). Framework for economic assessment of concrete waste management strategies. *Waste Management and Studies*, Vol. 37, p.268–277. https://doi.org/10.1177/0734242X18815962.

Erba, M. & Cantoni, S. (2019). Asbestos in freshwater fish of a pond in Milan. Where is it coming from? La Medicina del Lavoro. *Work, Environmental and Health*. Vol. 110, No. 3. p. 202–214, https://doi.org/10.23749/mdl.v110i3.7455

Erk, J. (2014) 'Federalism and decentralization in Sub-Saharan Africa: five patterns of evolution'. *Regional and Federal Studies*, Vol. 24, No. 5, p.535–552, doi: 10.1080/13597566.2014. 971769.

European Commission. (2008). Waste Framework Directive (2008/98/EC), European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098 (Accessed on 23/05/2023)

European Commission (2018). EU Construction and Demolition Waste Protocol and Guidelines. https://single-market-economy.ec.europa.eu/news/eu-construction-anddemolition-waste-protocol-2018-09-18_en (Accessed on 26 August 2023).

European Commission. (2015). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; European Commission: Brussels, Belgium. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614

European Commission. (2016). EU Construction & Demolition Waste Management Protocol. European Commission. https://single-market-economy.ec.europa.eu/news/eu-construction-and-demolition-waste-protocol-2018-09-18_en (Accessed on 14/05/2023)

European Commission. (2015). Closing the Loop - An EU Action Plan for the Circular Economy. https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF (Accessed on 25/04/2023)

Eurostat. (2009). European Communities. Statistics on focus. Kloek, W., Blumenthal, K. Environment and energy. Generation and treatment of waste. https://ec.europa.eu/eurostat/web/products-statistics-in-focus/-/ks-sf-09-030 (Accessed on 23/07/2023)

Eurostat. (2017). Generation of Waste-by-Waste Category, Hazardousness and NACE Rev 2 Activity. FERCD, 2015.

Fantaye, Y., Motuma, M., & Tsegaye, G. (2017). Land Use Land Cover Change Analysis using Geospatial Tools in Case of Asayita District, Zone one, Afar Region, Ethiopia. *Journal of Resources Development and Management*, Vol. 29, p.2422–8397.

Faulkner, S.P. & Richardson, C.J. (2020). Physical and Chemical Characteristics of Freshwater Wetland Soils. In D.A. Hammer (Eds), *Constructed Wetlands for Wastewater Treatment* (pp. 41 – 72). Boca Raton. https://doi.org/10.1201/9781003069850

Ferronato, N. & Torretta, V. (2019). 'Waste mismanagement in developing countries: a review of global issues.' *International Journal of Environmental Studies and Public Health*, Vol. 16, p.1060, doi: 10.3390/ijerph16061060.

Ferronato, N., Moresco, L., Lizarazu, G.E.G., Portillo, M.A.G., Conti, F., & Toretta, V. (2023). Comparison of environmental impacts related to municipal solid waste and construction and demolition waste management and recycling in a Latin American developing city. Vol, 30, p. 8548–8562, https://doi.org/10.1007/s11356-021-16968-8

Fitchett, A. (2017). SuDS for managing surface water in Diepsloot informal settlement, Johannesburg, South Africa. *Water SA*, Vol. 43, No. 2, http://dx.doi.org/10.4314/wsa.v43i2.14

Fitchett, A. & Rambuwani, P. (2022). Construction waste is costly: what's causing it on South African building sites. https://theconversation.com/construction-waste-is-costly-whats-causing-it-on-south-african-building-sites-191112 (Accessed on 15/02/2023).

Foody, G.M. (2002). Status of land cover classification accuracy assessment. Remote Sensing Environment. Vol. 80, No. 1, p.185–201, https://doi.org/10.1016/S0034-4257(01)00295-4

Fourways Review. (2017). Spend your Mandela Day helping the Green Neighbourhood clean-up Diepsloot wetlands. https://www.citizen.co.za/fourways-review/news-headlines/2017/07/03/spend-your-mandela-day-helping-the-green-neighbourhood-clean-up-diepsloot-wetlands/ (Accessed on 19/12/2023).

Gamil, Y. & Rahman, I.A. (2017). 'Identification of causes and effects of poor communication in construction industry: a theoretical review', *Emerging Science Journal*, Vol. 1, No. 4, p.239–247, doi: 10.28991/ijse-01121

Gamper, A. (2019). 'A 'global theory of federalism': the nature and challenges of a federal state', Special Issue German Federalism: Theory and Developments http://www.cambridge.org (accessed on 17 January 2023).

Gebresllassie, H., Gashaw, T., & Mehari, A. (2014). Wetland Degradation in Ethiopia: Causes, Consequences and Remedies. *Journal of Environment and Earth Science*, Vol. 4, No.11, p. 40–49.

Gisselman, F. (2015). The Value of the Flood Mitigation Services of Wetlands: Evidence from GIS-based Hedonic Price Analysis. https://www.diva-portal.org/smash/get/diva2:819683/FULLTEXT01.pdf (Accessed on 25 January 2024).

Global Health and Safety Initiative. (2008). Toxic Chemicals in Building Materials: An Overview for Health Care Organizations. https://healthybuilding.net/uploads/files/toxic-chemicals-in-building-materials.pdf (Accessed on 20/05/2023).

Godfrey, L. & Nahman, A. (2007). 'Are developing countries ready for first world waste policy instruments?', CISA 2007: Proceedings of Sardinia' in CISA, Eleventh International Waste Management and Landfill Symposium, Italy.

Godfrey, L., Giday, K., Ahmed, M.T., Katima, J., Oelofse, S., Osibanjo, O., Richter, U, H., & Yonli, A. (2019). *Solid Waste Management in Africa: Governance Failure or Development Opportunity*? In Edomah, E (Eds.) Regional Development in Africa, 3rd Edition. Intech Open Publishers, London. pp.1–14.

Godfrey, L., Scott, D. & Trois, C. (2013). 'Caught between the global economy and local bureaucracy: the barriers to good waste management practice in South Africa', *Waste Management and Studies*, Vol. 31, No. 3, p.295–305, doi: 10.1177/0734242X12470204.

Gohlke, O. & Martin, J. (2007). 'Drivers for innovation in waste-to-energy technology', *Waste Management and Studies*, Vol. 25, No.3, p.214–219, doi: 10.1177/0734242X07079146.

Govindan, K., Shankar, K. M., & Kanaan, D. (2016). Sustainable material selection for construction industry – A hybrid multi criteria decision making approach. *Renewable and Sustainable Energy Reviews,* Vol, 55, p.1274 – 1288, doi: 10.1016/j.rser.2015.07.100

Gray-Cosgrove, C., Liboiron, M., & Lepawsky, J. (2015). The Challenges of Temporality to Depollution & Remediation. *Surveys and Perspectives Integrating Environment and Society*, Vol, 8. No., p.1-10, http://journals.openedition.org/sapiens/1740

Grundling, A.T. (2011). Traditional water sources – lifeline in a time of need, The Water Wheel - September/October, Vol. 10, No. 5. p.36–39. (https://www.wrc.org.za/wp-content/uploads/mdocs/WW_Sep_2011_rural%20water.pdf)

Grundling, P. (2000). The quaternary peat deposits of Maputaland, Northern KwaZulu-Natal, South Africa: Categorisation, Chronology and Utilization, MSc thesis, Rand Afrikaans University, South Africa.

Guerra, B.C., Shahi, S., Mallaei, A., Skaf, N., Weber, O., Leite, F., & Haas, C. (2021). Circular economy applications in the construction industry: A global scan of trends and opportunities. *Journal of Cleaner Production*, Vol, 324, 129125, https://doi.org/10.1016/j.jclepro.2021.129125

Guerschman, J.P., Paruelo, J.M., Bella, C.D., Giallorenzi, M.C., & Pacin, F. (2003). Land cover classification in the Argentine Pampas using multi-temporal Landsat TM data. *International Journal Remote Sensing*. Vol. 23, No. 7, p.3381–3402. https://doi.org/10.1080/01431160210000212888

Gurney, R., Liley, S., Outram, K., & Mirfenderesky, A. (2021). Future of Construction: A Global Forecast for Construction to 2030. Marsh& Guy Capenter, Oxford Economics.

Hamilton, A., Madison, J., Jay, J., & Shapiro, I. (2009). The Federalist Papers, Yale University Press, New Haven, Connecticut, USA.

Heshmati, A. (2015). A Review of the Circular Economy and its Implementation. IZA Discussion Paper No. 9611, https://docs.iza.org/dp9611.pdf (Accessed on 16/01/2024).

Hoang, N. H., Ishigaki, T., Kubota, R., Tong, T. K., Nguyen, T.T., Nguyen, H.G., Yamada, M., & Kawamoto, K. (2020). Waste generation, composition, and handling in building-related construction and demolition in Hanoi, Vietnam. *Waste Management*, Vol. 117, p.32–41, doi.org/10.1016/j.wasman.2020.08.006

Hoorzook, K.B., Pieterse, A., Heine, L., Barnard, T. G., & van Rensburg, N. J. (2021). Soul of the Jukskei River: The Extent of Bacterial Contamination in the Jukskei River in Gauteng Province, South Africa. *International Journal of Environmental Studies and Public Health*, Vol. 18, No. 16. p. 8537, https://doi.org/10.3390/ijerph18168537

Hopkins, M. (2003). The Planetary Bargain – Corporate Social Responsibility Matters, Earthscan, London.

Hu, S., Niu, Z., Chen, Y., Li, L., & Zhang, H. (2017). Global wetlands: Potential distribution, wetland loss, and status. *Science of the Total Environment*, Vol. 586, p.319–327, http://dx.doi.org/10.1016/j.scitotenv.2017.02.001

Huang, B., Wang, X., Kua, H., Geng, Y., Bleischwitz, R., & Ren, J. (2018). Construction and demolition waste management in China through the 3R principle. *Resources, Conservation and Recycling*, Vol, 129, p.36–44, doi:10.1016/j.scitotenv.2017.02.001

Huberfeld, N., Gordon, S.H., & Jones, D.K. (2020). 'Federalism complicates the response to the COVID-19 health and economic crisis. what can be done', *Journal of Health Politics, Policy and Law*, Vol. 45, No. 6, p.951–965, doi. 10.1215/03616878-8641493.

Hwang, B. & Bao Yeo, Z. (2011). "Perception on benefits of construction waste management in the Singapore construction industry", *Engineering, Construction and Architectural Management*, Vol. 18, No. 4, p.394–406, doi:10.1108/09699981111145835

Hyder Consulting. (2011). Construction and Demolition Waste Status Report Management of Construction and Demolition Waste in Australia, Department of Sustainability, Environment, Water, Population and Communities, Department of Environment and Resource Management, Queensland. https://www.dcceew.gov.au/sites/default/files/documents/construction-waste.pdf (Accessed on 23/08/2022).

Iacoboaea C., Aldea M. and Petrescu F. (2019). Construction and Demolition Waste - A Challenge for the European Union? *Theoretical and Empirical Studies in Urban Management Volume*, Vol, 14, No, 1, p.30–52, https://um.ase.ro/no141/2.pdf

Illankoon, I.M.C.S., & Lu, W. (2019). Cost implications of obtaining construction waste management-related credits in green building. *Waste Management*, Vol. 102, p.722–731, https://doi.org/10.1016/j.wasman.2019.11.024

Intergovernmental Panel on Climate Change - IPCC. (2022). Climate Change: Mitigation of Climate Change. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg3/ (Accessed on 15/08/2023).

Intergovernmental Panel on Climate Change – IPCC. (2022). Climate Change. Impacts, Adaptation and Vulnerability. Summary for Policymakers, Technical Summary and Frequently Asked Questions, IPCC. https://www.ipcc.ch/report/ar6/wg2/ (Accessed on 21/03/2023).

IOL. (2023). Controversial Durban building firm fined R7.5m for dumping rubble in wetland. https://www.iol.co.za/news (Accessed on 4/01/2024).

Ishigaki, T. (2017). Urban Flood caused by Inappropriate Waste Management in Asia: Adaptation to Climate Change. Centre for Material Cycles and Waste Management Studies. National Institute for Environmental Studies, Japan. https://www.nies.go.jp/i-forum/jqjm1000000f9fxg-att/S1-2_Ishigaki.pdf (Accessed on 23/03/2023).

Ismail, Z., Ali, S., Zulfiqar, A., & El-Serehy, H.A. (2023). Impact of Cement Industries on Potentially toxic elements' contamination and other characteristics of topsoil: A Case Study. *Environmental Pollutants and Bioavailability*, Vol, 35, No.1, 2271664, doi.org/10.1080/26395940.2023.2271664

Jensen, J.R., J., Hardin, P., & Jensen, R.R., 2009. Image Classification, in: The SAGE Handbook of Remote Sensing. SAGE Publications, Inc., 1 Oliver's Yard, 55 City Road London EC1Y 1SP, p.269–281. https://doi.org/10.4135/9780857021052.n19

Jombo, S. & Adelabu, S. (2023). Evaluating Landsat-8, Landsat-9 and Sentinel-2 imageries in land use and land cover (LULC) classification in a heterogeneous urban area. *Geojournal*, Vol. 88, No.1, p.377–399, http://dx.doi.org/10.1007/s10708-023-10982-8

Kabirifar, K., Mojtahedi, M., Wang, C.C., & Tam, V.W.Y. (2021). 'Effective construction and demolition waste management assessment through waste management hierarchy; a case of Australian large construction companies.' *Journal of Cleaner Production*, Vol. 312, No.6, 127790, https://doi.org/10.1016/j.jclepro.2021.127790.

Kaluarachchi, M., Waidyasekara, A., Rameezdeen, R., & Chileshe, N. (2021). 'Mitigating dust pollution from construction activities: a behavioural control perspective', *Sustainability*, Vol. 13, No.16, 9005, https://doi.org/10/3390/su13169005.

Kanaujia, A. & Kumar, A. (2014). Wetlands: Significance, Threats and their Conservation. Green, Vol. 7, No.3, 1-24, file:///C:/Users/1546170/Desktop/GREENwetlands-Green2.pdf (Accessed 21/07/2023).

Katerusha, D. (2021). Barriers to the use of recycled concrete from the perspective of executing companies and possible solution approaches - case study Germany and Switzerland. *Resources Policy*, Vol, 23, 102212, https://doi.org/10.1016/j.resourpol.2021.102212

Kazan-Allen, L. (2019). Chronology of Asbestos Bans and Restrictions. International Ban Asbestos Secretariat. Asbestos Explained. http://ibasecretariat.org/asbestos_ban_list.php (Accessed on 25/06/2023)

Khan, Z, A. (2017). Causes and Consequences of Greenhouse Effect & Its Catastrophic Problems for Earth*. International Journal of Sustainability and Information Technologies*, Vol.3. No.4: p.34–39. doi: 10.11648/j.ijsmit.20170304.11

Kings, S. (2013). Rubble baron's dumping troubles pile up. Mail and Guardian, https://mg.co.za/article/2013-10-31-rubble-barons-dumping-troubles-pile-up/ (Accessed on 19/12/2023.

Kings, S. (2018). R700k wetland fine for luxury developer. Mail and Guardian, https://mg.co.za/article/2018-09-28-00-r700k-wetland-fine-for-luxury-developer/ (Accessed on 25/12/2023).

Kirchherr, J., Reike, D., & Hekkert, M. (2017). 'Conceptualizing the circular economy: an analysis of 114 definitions.' Resources, Conservation and Recycling, Vol. 127, p.221–232, http://dx.doi.org/10.1016/j.resconrec.2017.09.005.

Kirk, R. (2017). Diepsloot gets cleaned up in honour of Madiba. Fourways Review, https://www.citizen.co.za/fourways-review/news-headlines/2017/07/21/diepsloot-gets-cleaned-up-in-honour-of-madiba/ (Accessed on 20/12/2023).

Kolka, R., Trettin, C., & Windham-Myers, W. (2022). *The Importance of Wetland Carbon Dynamics to Society: Insight from the Second State of the Carbon Cycle Science Report*, In (Krauss, K.W., Zhu, Z. and Stagg, C.L. (eds). Wetland Carbon and Environmental Management. John Wiley & Sons Inc, pp.421–436.

Koma, S.B. (2010) 'The state of local government in South Africa: issues, trends and options', *Journal of Public Administration*, Vol. 45, No. 1. p.111–120.

Kubanza, N.S. (2021). 'The role of community participation in solid waste management in Sub-Saharan Africa: a study of Orlando East, Johannesburg, South Africa.' *South African Geographical Journal*, Vol. 103, No.1, p.223–236, https://doi.org/10.1080/03736245.2020.1727772.

Kubanza, N.S. & Simatele, D. (2015). 'Social and environmental injustices in solid waste management in sub-Saharan Africa: a study of Kinshasa, the Democratic Republic of Congo', Local Environment. *The International Journal of Justice and Sustainability*, Vol. 21, No. 7, p.866-899 doi: 10.1080/13549839.2015.1038985.

Kubanza, N.S. & Simatele, M.D. (2019). 'Sustainable solid waste management in developing countries: a study of institutional strengthening for solid waste management in Johannesburg, South Africa. *Journal of Environmental Planning and Management*, Vol. 63, No.2, p.175-188, doi: 10.1080/ 09640568.2019.1576510.

Kumar, A. & Kanaujia, A. (2014). Wetlands: Significance, Threats and their Conservation. A Quartely Newsletter, *Green*. Vol. 7, No. 3-4, p.1–25.

Labaran, Y.H., Mathur, V.S., Muhammad, U.S., & Musa, A.A. (2022). Carbon footprint management: A review of construction industry. *Cleaner Engineering and Technology*, Vol. 9, 100531, doi.org/10.1016/j.clet.2022.100531

Lalenti, V. (2020). Deep Time Reckoning. How Future Thinking Can Help Earth Now. The MIT Press, ISBN: 9780262539265

Laubscher, L.H. (2012). Challenges on financial control and accountability in South African municipalities. *Journal for New Generation Sciences*, Vol. 10, No. 1, p.63–79.

Let, M., & Pal, S. (2023). Socio-ecological well-being perspectives of wetland loss scenario: A review. *Journal of Environmental Management*. Vol. 326, 116692, doi.org/10.1016/j.jenvman.2022.116692

Liboiron, M. (2016). Redefining pollution and action: The matter of plastics. *Journal of Material Culture*, Vol. 21, No.1, p.1–24, doi: 10.1177/1359183515622966

Lillesand, T., Kiefer, R.W., & Chipman, J. (2015). Remote Sensing and Image Interpretation, 7th Edition, John Wiley & Sons.

Lolu, A. J., Ahluwalia, A.S., Sidhu, M.C., Reshi, Z., Shar, M.A., & Lolu, S.J. (2018). Wetlands: an imbroglio of interlinked carbon pools. *Tropical Ecology*, Vol. 59, No.3, p.383–395.

Low, J.K., Wallis, S.L., Hernandez, G., Cerqueira, I.S., Steinhorn, G., & Berry, T. (2020). 'Encouraging circular waste economies for the New Zealand construction industry. Opportunities and barriers. *Frontiers in Sustainable Cities*, Vol. 2, No. 35, p.1–7, doi: 10.3389/frsc.2020.00035.

Lu, W., & Tam, V. (2013). Construction waste management policies and their effectiveness in Hong Kong: a longitudinal review. *Renewable and Sustainable Energy Reviews*, Vol. 23, p.214–223, doi: 10.1016/J.RSER.2013.03.007.

Luo, Y., Wu, J., Wang, X., Zhao, Y., & Feng, Z. (2021). Understanding ecological groups under landscape fragmentation based on network theory. *Landscape and Urban Planning*, Vol. 210, 104066, doi.org/10.1016/j.landurbplan.2021.104066

Macozoma, D.S. (2006). Developing a Self-Sustaining Secondary Construction Materials Market in South Africa. Master of Science Dissertation, University of the Witwatersrand, Johannesburg.

Madebwe, C., & Madebwe, V. (2006). The battle for control of Zimbabwe's cities: exploring governance conflicts and causal links for Operation Murambatsvina (Operation Restore Order)', *International Journal of Geography and Environmental Management*, Vol. 3, No. 1, p.53–61, ISSN: 2504-8821 [online] http://www.iiardpub.org

Mah, C.M., Fujiwara, T., & Ho, C.S. (2018). Environmental Impacts of Construction and Demolition Waste Management Alternatives. *Chemical Engineering Transaction*, Vol. 63, p.343–348. doi: 10.3303/CET1863058

Mahayuddin, S.A., Badaruzzaman, W.H., Pereira, J.J., & Mokhtar, M. (2008). Construction waste management in a developing country: case study of Ipoh, Malaysia. *WIT Transactions on Ecology and the Environment*, Vol. 109, p.481–489, doi: 10.2495/WM080491.

Makhloufi, S. & Bouadam, R. (2022). Inert waste management in developing countries: from regulation to practice – the case of Constantine (Algeria). *International Journal of Innovative Studies in Sociology and Humanities*, Vol.7, No.11, p.2456–4931, doi.org/10.20431/2456-4931.071113.

Malhi, Y. (2017). Annual Review of Environment and Resources the Concept of the Anthropocene. *Annual Review of Environment and Resources*, Vol. 42, p.77–104, doi.org/10.1146/annurev-environ-102016-060854

Mandishona, E. & Knight, J. (2022). Feedbacks and Trade-Offs in the Use of Wetland Ecosystem Services by Local Communities in Rural Zimbabwe. *Sustainability*, Vol. 14, No.3, 1789, doi.org/10.3390/ su14031789

Mandishona, E. & Knight, J. (2022). Inland wetlands in Africa: A review of their typologies and ecosystem services. *Progress in Physical Geography*, Vol. 46, No, 4, p.547–565.

Mangoro, N & Kubanza, N.S. (2023). Community perceptions on the impacts of Solid Waste Management on Human Health and the Environment in Sub-Saharan African Cities: A study of Diepsloot, Johannesburg, South Africa. *Development Southern Africa*, Vol. 40, No. 6, p.1214–1233, doi: 10.1080/0376835X.2023.2219698

Marumahoko, S. (2020). Urban local government service delivery in Post-Mugabe Zimbabwe, in Farazmand, A. (Ed.): *Global Encyclopedia of Public Administration, Public Policy, and Governance*, Springer, Cham,pp.1–8.

Mathodi, V., John, S.E., Maya, K.K., & Padmalal, D. (2020). Environmental impact of quarrying of building stones and laterite blocks: a comparative study of two river basins in Southern Western Ghats, India. *Environmental Earth Sciences*, Vol. 79, No.14, 366, doi:10.1007/s12665- 020-09104-1

Mawed, M., Al Nuami, M.S. & Kashwni, G. (2020). Construction and demolition waste management in the UAE: application and obstacles. *International Journal of GEOMATE*, Vol. 18, No. 70, p.235–245, doi.org/10.21660/2020.70.45101

Mbwilo, E.C. & Mahenge, F.Y. (2022). Municipal solid waste collection services in rapidly growing cities of Tanzania. *Journal of the Geographical Association of Tanzania*, Vol. 42, No. 1, p.83–105, doi. 10.56279/jgat.v42i1.219

Koch, T. & Harrington, A. (1998). Reconceptualising rigour: The case for reflexivity. *Journal of Advanced Nursing,* Vol. 28. No. 4, p.882–890, doi.org/10.1046/j-1365-2468.1998.00725.x

McLean, C.T., Ground, L.E., Boon, R.G.C., Roberts, D.C., Govender, N., & McInnes, A. (2016). Durban's Systematic Conservation Assessment. EThekwini Municipality. Environmental Planning and Climate Protection Department, EThekwini Municipality, Durban. https://www.durban.gov.za/pages/search/environmental-planning-climate-protection (Accessed on 19/12/2023).

Mehra, S., Singh, M., Sharma, G., Kumar, S., Chadha, N., & Chadha, P. (2022). *Impact of Construction Material on Environment*. In Malik, J.A. & Marathe (eds.) Ecological and Health Effects of Building Materials, pp.427-442.

Mehran, D. (2016). Exploring the Adoption of BIM in the UAE construction industry for AEC firms. *Procedia Engineering,* Vol.145, No. p.1110–1118, doi: 10.1016/j.proeng.2016.04.144

Miller, F. (2021). The Industry Creating a Third of World's Waste. Future Planet – BBC. Available at www.bbc.com (Accessed on 11 July 2023).

Mitsch, W.J. & Gosselink, J.G. (2000). The Value of Wetlands: Importance of Scale and Landscape Setting. *Ecological Economics*, Vol. 35, No.1, p.25–33, doi.org/10.1016/S0921-8009(00)00165-8

Mlambo, V. (2018). An overview of rural-urban migration in South Africa: Its causes and implications. *Archives of Business Research*, Vol. 20, No. 6, p.63–70, doi:10.14738/abr.64.4407

Moagi, O. (2018). Concerns over wetland dumping. News24, https://www.news24.com/news24/concerns-over-wetland-dumping-20180127 (Accessed on 19/12/2023).

Mohammed, A. & Elias, E. (2017). Domestic waste management and its environmental impacts in Addis Ababa City. *African Journal of Environmental and Waste Management*, Vol. 4, No.3, p.206–216.

Montt, G., Fraga, S., & Harsdorff, M. (2018). The future of work in a changing natural environment: Climate change, degradation and sustainability. International Labour Organisation – ILO future of work studies paper series.

Morole, M., Yessoufou, K.Y., Bufo, S.A., Rampedi, I.T., & Modley, L. (2022). The impact of informal settlements on the surface water quality: a baseline analysis of the Kaalspruit in Tembisa township, South Africa. *Urban Water Journal*, Vol. 20, No.1, p.1–10, doi: 10.1080/1573062X.2022.2099289

Mosina, T. (2016). Diepsloot wetland clean-up programme promises to give children a playground. Fourways Review, https://www.citizen.co.za/fourways-review/ (Accessed on 19/12/2023).

Mucina, L., & Rutherford, M.C. (2006). The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia.

Muigai, R., Alexander, M., & Moyo, P. (2013). Cradle-to-gate environmental impacts of the concrete industry in South Africa. *Journal of the South African Institution of Civil Engineering*, Vol. 55, No.2 p.2–7.

Nahman, A., & Godfrey, L. (2010). Economic Instruments for Solid Waste Management in South Africa: Opportunities and Constraints. *Resources. Conservation and Recycling*, Vol. 54, No.8, p.521–531. doi.org/10.1016/j.resconrec.2009.10.009

Napier, T. (2016). Construction Waste Management. https://www.wbdg.org/resources/construction-waste-management (Accessed on 15/02/2023).

Ndou, V. & Rampedi, I. T. (2022). Bibliometric Analysis of Municipal Solid Waste Management Studies: Global and South African Trends. *Sustainability*, Vol. 14, No. 16, 10229, doi.org/10.3390/su141610229

Nelles, M., Grunesa, J., & Morschecka, G. (2016). 'Waste management in Germany – development to a sustainable circular economy?' International Conference on Solid Waste Management, 5IconSWM 2015. *Procedia Environmental Sciences*, Vol. 35, p.6–14, doi: 10.1016/j.proenv.2016.07.001

New Hampshire Department of Environmental Services. (2018). Fugitive Dust: Prevention, Abatement and Control. New Hampshire Department of Environmental Services, United States of America. https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/fugitive-dust-control.pdf (Accessed on 23/10/2023).

Ngcuka, O. (2021). 'It's a waste': Muizenberg residents rubbish wetland restoration effort. Daily Maverick, https://www.dailymaverick.co.za/article/2021-06-24-its-a-waste-muizenberg-residents-rubbish-wetland-restoration-effort/ (Accessed on 20/12/2023).

Niu, Z.G., Zhang, H.Y., & Wang, X.W. (2012). Mapping wetland changes in China between 1978 and 2008. *Chinese Science Bulletin*, Vol. 57, No.22, p.2813–2823, doi: 10.1007/s11434-012-5093-3

Nyangiwe, T., Amoah, C., & Mukumba, C.P. (2023). The Emergence of Construction Mafia in South Africa: The Implication on the Construction Industry. International *Journal of Architectural and Environmental Engineering,* Vol. 17, No.11, p.422–426.

Nyika, J.M., Onyari, E. K. Mishra, S., & Dinka, M. O. (2019*). Waste Management in South Africa*. In Pariatamby, A., Hamid, F.S. and Bhatti, M.S. (eds) Sustainable Waste Management Challenges in Developing Countries. Pennsylvania, IGI Global Publishers, pp.327–351.

OECD. (1996). Development Assistance Committee Organisation for Economic Co-operation and Development. Guidelines for aid agencies for improved conservation and sustainable use of tropical and sub-tropical wetlands. https://www.cbd.int/doc/guidelines/fin-oecd-gd-lns-wlands-en.pdf (Accessed on 23/08/2023)

Othman R. & Ameer, R. (2009). Corporate social and environmental reporting: Where are we heading? A survey of the literature. *International Journal of Disclosure and Governance*, Vol. 6: No. 4, p298–320, doi: 10.1057/jdg.2009.7

Ouda, O.K.M., Peterson, H.P., Rehan, M., Sadef, Y., Alghazo, J.M., & Nizami, A.S. (2018). A case study of sustainable construction waste management in Saudi Arabia. *Waste Biomass Valorization*, Vol. 9, No.7, p.2541–2555, doi.org/10.1007/s12649-017-0174-9

Oyenuga, A.A., & Bhamidiarri, R. (2015). Sustainable approach to managing construction and demolition waste: an opportunity or a new challenge?', *International Journal of Innovative Studies in Science, Engineering and Technology*, Vol. 4, No.11, p.10368–10378, doi: 10.15680/ijirset.2015.041100

Pacheco-Torgal, F., & Jalali, S. (2011). Toxicity of building materials: a key issue in sustainable construction. *International Journal of Sustainable Engineering*, Vol. 4, No.3, p.281-287, doi: 10.1080/19397038.2011.569583

Papargyropoulou, E., Preece, C.N., Padfield, R., & Abdullah, A. (2011). Sustainable construction waste management in Malaysia: a constructor's perspective. Conference:

Proceedings of the MISBE 2011-International Conference on Management and Innovation for a Sustainable Built Environment. https://www.irbnet.de/daten/iconda/CIB22163.pdf (Accessed on 23/05/2023).

Park, P. & Tucker, R. (2016). Overcoming barriers to the reuse of construction waste material in Australia: a review of the literature. *International Journal of Construction Management*, Vol. 17, No. 3, p.228–237, doi: 10.1080/15623599.2016.1192248.

Penfound, E. & Vas, E. (2023). Modelling future wetland loss with land use landcover change simulation in the Greater Toronto and Hamilton Area: The importance of continued greenbelt development restrictions. *Habitat International*, Vol. 143, No.1, 102974, https://doi.org/10.1016/j.habitatint.2023.102974

Peng, Z., Lu, W & Webster, C. (2022). Understanding the effects of a construction waste cap-and-trade scheme: An agent-based modelling study in Hong Kong. *Journal of Cleaner Production*. Vol. 375, No. 15, 134135, doi.org/10.1016/j.jclepro.2022.134135

Ponnada, M.R. & Kameswari, P. (2015). Construction and Demolition Waste Management – A Review. *International Journal of Advanced Science and Technology*, Vol. 84, p.19-46, doi.org/10.14257/ijast.2015.84.03

Rabbane, G., Kabir, A., Al-Mamun, H., & Mustafa, G. (2022). Toxic Effects of Arsenic in Commercially Important Fish Rohu Carp, Labeo rohita of Bangladesh. *Fishes*, Vol. 7, No.5, 217, doi.org/10.3390/fishes7050217

Rahman MTU, Tabassum F, Rasheduzzaman M, Saba H, Sarkar L., & Ferdous. J. (2017). Temporal dynamics of land use/land cover change and its prediction using CA-ANN model for southwestern coastal Bangladesh. *Environmental Monitoring and Assessment*. Vol.189, No. 565, doi: 10.1007/s10661-017-6272-0

Rangecroft, S., Rohseb, M., Banks, E.W., Dayd, R., Di Baldassarree, G., Frommeng, T., Hayashih, Y., Höllermanni, B., Lebekg, K., Mondinoe, E., Ruscae, M., Wensj, M. & Van Loo, A.F. (2021). Guiding principles for hydrologists conducting interdisciplinary studies and fieldwork with participant. *Hydrological Sciences*, Vol.66, No.2, p.214–225, doi.org/10.1080/02626667.2020.1852241

Rasmeni, Z.Z. & Madyira, D.M. (2019). 'A review of the current municipal solid waste management practices in Johannesburg City Townships.' *Procedia Manufacturing*, Vol. 35, No.1, p.1025–1031, doi: 10.1016/j.promfg.2019.06.052

Rebelo, L.M., McCartney, M., & Finlayson, M. (2010). Wetlands of Sub-Saharan Africa: Distribution and contribution of agriculture to livelihoods. *Wetlands Ecology and Management*, Vol, 18, No. 5, p.557–577, doi.org/10.1007/s11273-009-9142-x

Rivers-Moore, N.A., & Cowden, C. (2012). Regional prediction of wetland degradation in South Africa. *Wetlands Ecology and Management*, Vol. 20, No.6, p.491-502, doi 10.1007/s11273-012-9271-5

Rizos, V., Tuokko, K., & Behrens, A. (2017). The Circular Economy A review of definitions, processes and impacts. Studies Report: Thinking Ahead of Europe, https://aei.pitt.edu/85892/1/RR2017-08_CircularEconomy_0.pdf (Accessed on 16/ 01/2024).

Roberts, B., Greehalgh, E., & Mead, E. (2004). Industrial ecology seeks to achieve sustainable development by discontinuing activities that endanger ecological processes fundamental to the stability of human life and natural eco-systems. *Journal of Cleaner Production*, Vol. 12, Vol. 8, p.997–1010, doi.org/10.1016/j.jclepro.2004.02.037

Rohracher, H. (2001). 'Managing the technological transition to sustainable construction of buildings: a sociotechnical perspective.' *Technology Analysis and Strategic Management*, Vol. 13, No. 1, p.137–150, doi.org/10.1080/09537320120040491

Rondinel-Oviedo, D.R. (2021). 'Construction and demolition waste management in developing countries: a diagnosis from 265 construction sites in the Lima metropolitan area', *International Journal of Construction Management*, Vol. 23, No.2, p.371-382, doi:10.1080/15623599.2021.1874677.

Rusen, J. (2006). Humanism and nature – some reflections on a complex relationship*. Journal for Transdisciplinary Studies in Southern Africa.* Vol. 2, No. 2. a278, doi: 10.4102/td.v2i2.278

Saad, A., Bal, M. & Khatib, J. (2022). 'The need for a proper waste management plan for the construction industry: a case study in Lebanon', *Sustainability,* Vol. 14, No.19, p.1-17, doi: 10.3390/su141912783.

Sakanyi, G. & Kooma, E.H. (2022). 'Challenges and opportunities associated with solid waste management in Chililabombwe District, Zambia', Textila *International Journal of Public Health*, Vol. 10, No. 2, doi:10.21522/TIJPH.2013.10.02. Art030.

Schalles, J.F. (1989). *The Chemical Environment of Wetlands*. In, (eds.) Majumdar, R.P., Brenner, F.J. & Tiner, R.W. Wetlands Ecology and Conservation. Emphasis in Pennsylvania. Pennsylvania. The Pennsylvania Academy of Science, pp.75–92.

Schuyt, K. (2004). Economic consequences of wetland degradation for local populations in Africa. *Ecological Economics*, Vol. 53, No.2, p.177–190, https://doi.org/10.1016/j.ecolecon.2004.08.003

Simion, I. M, Fortuna, M. E., & Bonoli, A. (2013). Comparing environmental impacts of natural inert and recycled construction and demolition waste processing using LCA. *Journal of Environmental Engineering and Landscape Management*, Vol, 21, No. 4, p.273–287, https://doi.org/10.3846/16486897.2013.852558

Singh, R.K., Premakumara, D.G.J.P., Yagasa, R., & Onogawa, K. (2022). Study of Waste Management in Phnom Pehn, Cambodia [online] http://www.ccet.jp (accessed 4/09/ 2023).

Sokwanele (2005) Zimbabwe: Operation Murambatsvina – An Overview and Summary [online] http://reliefweb.int (accessed 4/09/2023).

Sinthumule, N.I., & Netshisaulu, K.H. (2022). Wetland Resource Use and Conservation Attitudes of Rural vs. Urban Dwellers: A Comparative Analysis in Thohoyandou, Limpopo Province, South Africa. *Water*, Vol. 14, No.8, 1290. https://doi.org/10.3390/w14081290

Sithirith, M. (2015). The Governance of Wetlands in the Tonle Sap Lake, Cambodia. *Journal of Environmental Science and Engineering* B, Vol, 4, p.331-346, doi:10.17265/2162-5263/2015.06.004

Skowno, A.L., Poole, C.J., Raimondo, D.C., Sink, K.J., Van Deventer, H., Van Niekerk, L., Harris, L.R., Smith Adao, L.B., Tolley, K.A., & Zengeya, T.A. (2018). The Status of South Africa's Ecosystems and Biodiversity; Synthesis Report; South African National Biodiversity Institute: Pretoria, South Africa, p.1–214. https://www.sanbi.org/wp-content/uploads/2019/10/NBA-Report-2019.pdf (Accessed on 23/07/2022).

Solitude Lake Management. How to Control Invasive Wetland Plants, Phragmites and Purple Loosestrife. https://www.solitudelakemanagement.com/ (Accessed on 21/12/23).

South African Government. (1996). White Paper on Sustainable Forest Development in South Africa. Republic of South Africa, https://www.gov.za/documents/white-papers/sustainable-forest-development-south-africa-white-paper-01-mar-1996 (Accessed on 15/12/2023).

South African Landscapers Institute – SALI. (2020). Wet-land-grab and the degradation of the Witwatersrand watershed. https://www.sali.co.za/about-sali/sali-news/ (Accessed on 6/12/2023).

Spisakova, M., Mesaros, P., & Mandikak, T. (2021). Construction Waste Audit in the Framework of Sustainable Waste Management in Construction Projects—Case Study. *Buildings*, Vol, 11, No. 11, 61, doi.org/10.3390/buildings11020061

Staunton, J. (2015). Infilling wetlands with construction and demolition (C&D) waste: Influence on land use, plant/dipteran communities and metal contamination. PhD Thesis. University of Galway. https://aran.library.nuigalway.ie/handle/10379/4909, Accessed on 21/04/2023)

Staunton, J., Williams, C.D., Mc-Donnell, R.J., Fleming, G.T.A., Henry, T., & Gormally, M.J. (2014). 'Challenges in assessing ecological impacts of construction and demolition waste on wetlands: a case study.' *Applied Ecology and Environmental Studies*, Vol. 12, No. 2, p.457-479, doi: 10.15666/aeer/1202_457479

Steinfeld, C.M.M. & Kingsford, R.T. (2013). Disconnecting The Floodplain: Earthworks and Their Ecological effect On a Dryland Floodplain in The Murray–Darling Basin, Australia. *River Studies and Applications,* Vol,9, p.206–218, https://doi.org/10.1002/rra.1583

Styger, G. (2019). Diepsloot 2030—Local Action in a South African Township. https://plussocialgood.medium.com/diepsloot2030-local-action-in-a-south-african-township-cedbce443ae (Accessed on 11/12/2023).

Suman, S. (2020). Construction and Demolition Waste and its Impact on Environment. *International Journal of Creative Studies Thoughts*. Vol, 8, No. 8, p.3674-3681.

Support-to-Life. (2023). Turkey-Earthquake: Emergency Situation Report. https://reliefweb.int/report/turkiye/turkey-earthquake-emergency-situation-report-17022023 (Accessed on 20/05/2023).

Teresa, A.R.E., Vasanth, G.D.N.J., & Vidya, C. (2020). A review on the potential effects of tsunami on built environment. *Materials Today Proceedings*, Vol. 33, No. 36, doi.org/10.1016/j.matpr.2020.06.019

The Times of India. (2018). Lack of Access to Finance key Hurdle in Municipal Solid Waste management: Study http://m.timesofindia.com (accessed 4/9/2023).

Tischer, A., Besiou, M., & Graubner, C.A. (2013). 'Efficient waste management in construction logistics: a refurbishment case study.' *Logistics Studies*, Vol. 6. No.4, p.159–171, doi: 10.1007/ s12159-013-0105-5.

Turner and Townsend. (2018). International construction market survey 2018. Turner and Townsend. https://aaqs.org/wp-content/uploads/2020/05/internationalconstruction-market-survey-2018.pdf (Accessed on 23/07/2023)

UN-DESA. (2019). Potential impact of later childbearing on future population. No. 2019/5. https://www.un.org/en/development/desa/population/publications/pdf/popfacts/PopFacts_2019-5.pdf (Accessed on 25/07/2023).

UNEP. (2019). Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources. Geneva, Switzerland. United Nations Environment Programme – UNEP. https://wedocs.unep.org/20.500.11822/28163 (Accessed on 16/07/2023).

UNICEF. (2023). War has hampered education for 5.3 Million Children in Ukraine. Press Release. https://www.unicef.org/ukraine/en/press-releases/war-has-hampered-education (Accessed on 20/05/2023).

United Nations Department of Economic and Social Affairs – UNDESA. (2017). World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100. https://www.un.org/en/desa/world-population-projected-reach-98-billion-2050-and-112-billion-2100 (Accessed on 06/12/2023).

United Nations Environmental Program – UNEP. (2023). Building a Sustainable Future: Unlocking Africa's Potential in the Construction Industry. https://globalabc.org/news/building-sustainable-future-unlocking-africas-potential-construction-industry (Accessed on 5/ 12/ 2023).

United States Department of Health and Human Services - USDHHS. (2014). Case Studies in Environmental Medicine (CSEM) Asbestos Toxicity. https://www.atsdr.cdc.gov/csem/asbestos_2014/docs/asbestos.pdf (Accessed on 16/07/2023)

United States Geological Survey USGS. (2013). Landsat 8. https://www.usgs.gov/landsat-missions/landsat-8 (Accessed on 09/01/2024).

United States Geological Survey USGS. (2018). USGS EROS Archive - Landsat Archives - Landsat 4-5 Thematic Mapper (TM) Level-1 Data Products. https://www.usgs.gov/centers/eros/science/usgs-eros-archive-landsat-archives-landsat-4-5-thematic-mapper-tm-level-1-data#overview (Accessed on 09/01/2024).

Upstill-Goddard, J., Glass, J., Dainty, A.R.J., & Nicholson, I. (2012). 'Integrating responsible sourcing in the construction supply chain', in Smith, S.D. (Ed.): Proceedings of 28th Annual ARCOM Conference, 3–5 September, Association of Researchers in Construction Management, Edinburgh, UK, p.1311–1319.

US-Environmental Protection Agency (EPA). (2022). Managing Storm Water and Dust at Demolition Sites. http://www.epa.gov/ (accessed 14 July 2023).

Van Vuuren, L. (2014). Mpumalanga wetland rehab partnership a win for ecological infrastructure. *Council for Scientific and Industrial Studies*. https://www.wrc.org.za/wp-content/uploads/mdocs/WWJuly2014_zaalklap.pdf (Accessed on 19/12/2023)

Wahlström, M., Bergmans, J., Teittinen, T., Bacher, J., Smeets, A., & Paduart, A. (2020). Construction and Demolition Waste: challenges and opportunities in a circular economy. Eionet Report - ETC/WMGE 2020/1

Wahlstrom, M., Teittinen, T., Kaartinen, T., & van Cauwenberghe, L. (2019). Hazardous Substances in Construction Products and Materials: PARADE. Best Practices for Pre-demolition Audits ensuring High Quality Raw Materials. EIT https://cris.vtt.fi/ws/files/27439115/EIT_RM_PARADE_Hazardous_substances_in_construction_Final_2019.pdf (Accessed on 23/12/2022)

Wang, H., Xia, S., Zhang, Q., &Zhang, P. (2022). Has China's Construction Waste Change Been Decoupled from Economic Growth? *Buildings*, Vol, 12, No.2, 147, doi.org/10.3390/buildings12020147

Wang, L. & Xi, C. (2020). Discussion on Classification System of Construction Waste in China. IOP Conference: *Earth and Environmental Science*, Vol. 555, 012054, doi:10.1088/1755-1315/555/1/012054

Wang, Q.F. & Qin, S. (2018). Comparative analysis of construction waste recycling policies at home and abroad. Proceedings of the International Workshop on Environmental Management, Science and Engineering (IWEMSE-2018), p.393–400, ISBN: 978-989-758-344-5.

Water Studies Commission. (2016). Limiting and mitigating the impact of coal mines on wetland. Water Studies Commission. https://www.wrc.org.za/wp-content/uploads/mdocs/TB_2230_Limiting%20the%20impact%20of%20coal%20mines%20on%20wetlands.pdf (Accessed on 23/12/2023).

Wechsler, S. (2003). Perceptions of digital elevation model uncertainty by DEM users. *URISA Journal*, Vol. 15, No.2, p.57–64, https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=4b2b206a37d6220de2c97f6a82832731dca85565 (Accessed on 17/09/2023)

Wessels, K., van den Bergh, F., Roy, D., Salmon, B., Steenkamp, K., MacAlister, B., Swanepoel, D., Jewitt, D., Wessels, K.J., van den Bergh, F., Roy, D.P., Salmon, B.P., Steenkamp, K.C., MacAlister, B., Swanepoel, D., & Jewitt, D. (2016). Rapid Land Cover Map Updates Using Change Detection and Robust Random Forest Classifiers. *Remote Sensing*. Vol. 8, No.11, 888. https://doi.org/10.3390/rs8110888

Wetlands International. (2010). Wetlands and Water, Sanitation and Hygiene (WASH) – understanding the linkages. *Wetlands International*, www.wetlands.org (Accessed on 26/08/2023).

Whyte CR, Shepherd JK. (1999). An inventory of the wetlands in the Mkomazi catchment of KwaZulu-Natal. Town and Regional Planning Commission, Pietermaritzburg.

World Health Organisation. (2023). Surveillance System for Attacks on Health Care (SSA). https://www.who.int/emergencies/surveillance#:~:text=Surveillance%20System%20of%20Attacks%20on,of%20attacks%20on%20health%20care. (Accessed on 20 May, 2023).

Worrall, L., Colenbrander, S., Palmer, I. Makene, F., Mushi, D., Kida, T., Martine, M. and Godfrey, N. (2017). Better Urban Growth in Tanzania a Preliminary Exploration of the Opportunities and Challenges, Coalition for Urban Transitions, A New Climate Economy Special Initiative. https://coalitionforurbantransitions.org/wp-content/uploads/2019/08/NCE2017-Better-Urban-Growth-Tanzania_final.pdf (Accessed on 27/08/2023).

WWF. (2018). World's wetlands disappearing three times faster than forests. https://wwf.panda.org/wwf_news/?335575/Worlds-wetlands-disappearing-three-times-faster-than-forests (Accessed on 10/01/2024).

Yetman, C.A., & Ferguson, J.W.H. (2011a). Spawning and non-breeding activity of adult giant bullfrogs (Pyxcephalus adspersus). *African Journal of Herpetology*, Vol. 60, No.1, p.13-29, https://doi.org/10.1080/21564574.2010.550324

Yuan, H. & Shen, L. (2011). 'Trend of the studies on construction and demolition waste management.' *Waste Management,* Vol. 31, No.4, p.670–679, https://doi.org/10.1016/j.wasman. 2010.10.030.

Zhang, S., Li, Z., Ning, X., & Li, L (2021). Gauging the impacts of urbanization on CO2 emissions from the construction industry: Evidence from China. *Journal of Environmental Management*, Vol, 288, 112440. https://doi.org/10.1016/j.jenvman.2021.112440

Zhao, W., Leeftink, R.B., & Rotter, V.S. (2010). 'Evaluation of the economic feasibility for the recycling of construction and demolition waste in China – the case of Chongqing.' *Resources. Conservation. Recycling*, Vol. 54, No. 6, p.377–389.

Zhu, J., Hou, J., Cai, A., Zhang, Y., Liu, D., Lu, D., & Zheng, X. (2023). Two-stage assessment: Towards a novel and holistic evaluation of urban geographically isolated wetland sustainability under global warming-induced dryness and loss. *Journal of Cleaner Production,* Vol. 434, No.6, 140035, https://doi.org/10.1016/j.jclepro.2023.140035

Zungu, M.M., Maseko, M.S.T., Kalle, R., Ramesh, T., & Downs, C.T. (2020). Effects of landscape context on mammal richness in the urban forest mosaic of eThekwini Municipality, Durban, South Africa. *Global Ecology and Conservation*, Vol. 21, e00878, https://doi.org/10.1016/j.gecco.2019.e00878

**APPENDICES**

**APPENDIX A**

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

**Participant Information Sheets for Studies**

NB: This Participant Information Sheet was deployed to participants who participated in this study regardless of their institution or organization.

**RE: Invitation to participate in a studies study titled "A Geographical Analysis of the Impacts of Demolition Waste on Wetland Functionality in South Africa: A Study of Gauteng Province."**

Dear Sir/Madam,

My name is Ngonidzashe Mangoro, a PhD in Geography and Environmental Studies student in the School of Geography, Archaeology and Environmental Studies at the University of the Witwatersrand in Johannesburg. As part of my studies, I am required to undertake a studies project which speaks to the above-mentioned degree program. This said, I am investigating the impacts of demolition waste on wetland functionality in Diepsloot and Tembisa townships in Johannesburg.

Given the above, I am writing to invite you to participate in a telephonic, online or one to one interview depending on the COVID-19 national regulations or your preference at the time of data collection. This process will be undertaken at the financial costs of the study investigator, and you will therefore not be required to incur any costs. However, should you choose an online interview (Microsoft Teams, Zoom or Skype), you will be required to have internet connection which may mean some costs on your end. The interview process will take approximately 30 minutes. You will not receive any direct benefits for participating in this studies study, and there are no disadvantages or penalties for not participating.

The study investigator would like to request for your permission to audio record the interview whether it is done in person or virtually. The study investigator would also like to request for photographs of wetlands polluted with construction and demolition waste in the three case study areas of Diepsloot, Tembisa and Alexandra if you have them. Please note that you have the right to accept or decline this request. You will be requested to state your decision regarding this request on the 'Consent Form' which needs your signature for authentication. Regarding your personal security, whatever interview platform used, the studies write-up process will be guided by anonymity and confidentiality. Therefore, your name, or any other identifiable information will not be disclosed. Your name will be substituted with a false one (pseudonym) in my write ups. Furthermore, the transcripts will be scanned and uploaded onto password secured cloud, and the physical copies will be stored in a lockable security cabinet at the university of the Witwatersrand. If you are happy for the information you will provide to be used anonymously by other researchers in the future, it will be made available to them with all identifiers removed. If you feel uncomfortable with the information being shared in the future for future studies purposes, please feel free to let me know. If at any point you are uncomfortable with any question, you do not need to answer it and if you want to stop the telephonic or online interview we can stop at any time.

If you have any queries after the interview, please kindly feel free to contact me or my supervisor on the below listed contact details. The study will be compiled into a study report which will be available on the University of the Witwatersrand's 'Wired space' website. Furthermore, parts of the study will be published in accredited international studies journals. I will provide you with the details once the articles have been published. If you wish to receive a summary of this report, I will be happy to send it to you upon request. If you have any queries, concerns, or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Studies Ethics Committee (non-medical), telephone + 27(0)11 717 1408, email address: hrecnon-medical@wits.ac.za.

Yours sincerely,

Study Investigator,

Ngonidzashe Mangoro

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**APPENDIX B**

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

**CONSENT FORMS**

Telephonic/ One to one Interview

Invitation to participate is a PhD studies study titled "A Geographical Analysis of the Impacts of Demolition Waste on Wetland Functionality in South Africa: A Study of Gauteng Province."

I……………………………………………………., agree to be a respondent in the above-mentioned studies study. Mr. Ngonidzashe Mangoro, a PhD in Geography and Environmental Studies student at the University of the Witwatersrand invited me to participate in the study because I am an expert in the field of environmental management and sustainability in South Africa. As agreed with him, I will participate in this study through either a telephonic interview or one to one interview depending on the national COVID-19 pandemic guidelines. I have been notified of my right to withdraw from the studies process at any time I wish. Furthermore, I have been notified of my right to confidentiality and anonymity, and as such, my decision is indicated below:

**PLEASE TICK ONE**

| | | |
|---|---|---|
| I agree that the student may use anonymous quotes in his report | YES | NO |
| I agree that the information I provide may be used anonymously by other researchers following this study | YES | NO |
| I agree that the researchers may audio record this interview | YES | NO |
| I agree to provide the studies with access to photographs of Wetlands polluted with construction waste if I have them | YES | |

Participant's signature………………….. Student's Signature……………………………..

Date ……………………………….. Date……………………………………………………………..

**TELEPHONIC OR ONLINE INTERVIEWS**

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

**QUESTIONS FOR NATIONAL GOVERNMENT AUTHORITIES**

**SECTION A**

Participant profile

1. What is your gender?

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2. What is your highest level of education?

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3. What position do you hold at your organization and what are your responsibilities?

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4. How long have you been in your industry?

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5. What types of solid waste do you work with more often?

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6. What environmental remedial work have you featured in since you joined your industry?

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**SECTION B**

1. What laws or regulations govern the demolition of structures and what measures are taken to implement them?

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2. What challenges does the national government face in managing demolition waste in South Africa?

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3. Who is primarily responsible for demolition waste management in South Africa and is there policy articulating this?

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4. There are widespread cases of dumping demolition waste in wetlands across South Africa. What work has been done by the national government to mitigate this?

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5. What steps have been taken by the national government to support a transition to the circular economy in the construction and demolition industry

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6. What is the state of water quality in Johannesburg aquatic water ecosystems?

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7. Is there a taskforce comprising government departments and private environmental organisations for the management of wetlands and other water resources in relation to waste management?

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8. Is there gazetted policy designed specifically to manage or conserve wetland ecosystems against threats from human activities in South Africa?

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9. What can the national government do to improve the conservation of wetland ecosystems in South Africa regarding solid waste management?

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APPENDIX C

TELEPHONIC OR ONLINE INTERVIEW SCHEDULE

CONSTRUCTION AND DEMOLITION ORGANISATIONS

SECTION A

**Participant profile**

1. What is your gender?

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2. What is your highest level of education?

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3. What position do you hold at your organisation and what are your responsibilities?

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4. How long have you been in your industry?

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5. Are you guided by the environmental sustainability concept in managing waste?

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## SECTION B

**Questions for demolishers and constructers**

1. Is the demolition process monitored by government authorities or an independent observer?

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2. Who is responsible for demolition waste disposal after the demolition process?

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3. What are the pre-demolition procedures or audits that you follow to reduce significant waste output?

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4. What measures do you have in place to ensure that demolition waste reaches landfills?

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5. Do you recycle waste and, if so, what challenges do you face?

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6. Are constructors and demolishers working together to manage waste in Johannesburg? Please explain how.

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7. Why is there widespread dumping of construction and demolition waste in Johannesburg?

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8. Why is there widespread demolition waste dumping in wetlands across Johannesburg?

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**APPENDIX D**

**TELEPHONIC OR ONLINE INTERVIEWS**

**PARASTATALS**

**SECTION A**

Participant profile

1. What is your gender?

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2. What is your highest level of education?

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3. What position do you hold at your organisation and what are your responsibilities?

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4. How long have you been in your industry?

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5. Do you belong to a network/ association of organisations that promote sustainable environmental utilisation?

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6. What types of solid waste is mostly dumped in wetlands across Johannesburg?

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7. What environmental remediation work in Johannesburg have you featured in since the last 10 years?

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**SECTION B**

1. In your view, how does demolition waste end up in wetlands across Johannesburg?

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2. In your view, why are wetlands targeted for demolition waste dumping across Johannesburg?

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3. What action have you taken to stop or limit the illegal disposal of rubble in wetlands?

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4. What is the state of water safety/ quality in Johannesburg aquatic water ecosystems?

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5. What remedial action efforts have you made to rehabilitate wetlands polluted with demolition waste?

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6. Are there laws in South Africa that particularly address the waste management issues from the construction and demolition sector?

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7. What has the national or local government departments done to address wetland pollution in wetlands in Johannesburg?

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8. How should communities be involved in waste management programmes in Johannesburg?

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9. How do the current waste laws or regulations address demolition waste management issues?

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10. How ecologically important are wetlands in Johannesburg?

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11. What is the effect of demolition waste dumping on wetland functionality in Johannesburg?

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12. What can be done to protect wetland ecosystems from illegal waste dumping?

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13. What can be done to reduce or totally alleviate demolition waste production in the context of Johannesburg?

**APPENDIX E**

TELEPHONIC/ONLINE / ONE TO ONE INTERVIEWS

LOCAL GOVERNMENT ORGANISATIONS

**SECTION A**

Participant profile

1. What is your gender?

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2. What is your highest level of education?

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3. What position do you hold at your organisation and what are your responsibilities?

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4. How long have you been in your job?

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5. Do you belong to a network of organisations that promote sustainable environmental utilisation?

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6. What types of solid waste do you work with more often?

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7. What environmental remedial work have you featured in since you joined your industry?

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**SECTION B**

1. What laws or regulations govern the demolition of structures and what measures are taken to implement them?

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2. Do you monitor solid waste management activities by the construction and demolition sector in Johannesburg?

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2.1. If yes, how do you do this?

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3. What are the challenges faced by the local government in managing construction and demolition waste?

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4. What steps have been taken by the local government to support a transition to the circular economy in the construction and demolition industry?

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4.1. If there are some measures, what action is taken to ensure compliance to these directives?

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5. Why do you think there has been increased dumping of demolition waste across Gauteng in the past 10 years?

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6. Who are the stakeholders responsible for demolition waste management in South Africa and is there policy articulating this?

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7. There are widespread cases of dumping demolition waste in wetlands across Johannesburg. What work has been done by to mitigate this?

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8. Does the local government have a strategy for wetland conservation across Gauteng particularly in relation to solid waste management?

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8.1. If a strategy exists, what does it entail, and which stakeholders are involved?

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9. Is there a law or gazetted policy designed specifically to manage or conserve wetland ecosystems against threats from human activities in South Africa?

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10. What is the state of water safety/ quality in Johannesburg aquatic water ecosystems?

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10.1. If the quality is bad or compromised, what is contributing to this?

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11. What can the local governments in South Africa do to improve the conservation of wetland ecosystems in South Africa?

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# Appendix F

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Research Office

**HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)**
R14/49 Mangoro

| | |
|---|---|
| **CLEARANCE CERTIFICATE** | **PROTOCOL NUMBER: H22/07/19** |
| **PROJECT TITLE** | A Geographical Analysis of the Impacts of Demolition Waste on Wetland Functionality in South Africa: A Study of Gauteng Province |
| **INVESTIGATOR(S)** | Mr N Mangoro |
| **SCHOOL/DEPARTMENT** | Geography, Archaeology and Environmental Studies/ |
| **DATE CONSIDERED** | 22 July 2022 |
| **DECISION OF THE COMMITTEE** | Approved<br>Risk Level: Low |
| **EXPIRY DATE** | 21 May 2026 |

**DATE** 22 May 2023 **CHAIRPERSON** ______________________
(Professor J Watermeyer)

cc: Supervisor : Prof M Simatele and Dr S Kubanza

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**DECLARATION OF INVESTIGATOR(S)**

To be completed in duplicate and **A SIGNED COPY** returned to the Secretary electronically. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure be contemplated from the research procedure as approved I/we undertake to submit an amendment of the protocol to the Committee. **I/we agree to completion of a regular progress report. For Minimal and Low Risk studies, this is due annually on 31 December. For Medium and High Risk studies, this is due twice annually on 30 June and 31 December.**

______________________ ______/______/______
**Signature** **Date**

**PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES**