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Exploring wetland change in the Gauteng Province, South Africa

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ABSTRACT

This study investigated land use and land cover changes in the Gauteng Province of South Africa with emphasis on wetland ecosystems. Using Landsat images and various image manipulation software such as ArcGIS and ENVI, this study conducted a predictive analysis of the potential state of wetland ecosystems in the Gauteng Province of South Africa by year 2040, using illegal dumping trends in the last 20 years. Based on this methodological framework, it is found that continued illegal dumping trends would lead to an almost total disappearance of wetlands in the study area by 2040. It is argued that despite the pro-environmental initiatives introduced in the early 2000s to conserve wetlands in South Africa, wetland deterioration has increased rapidly due to the associated methodological flaws, which further supports the findings of this study. Ultimately, it is recommended that a collaborative approach to wetland conservation, and a robust methodological shift are required to mitigate the threats faced by wetlands in the Gauteng Province of South Africa, and the model can be deployed across developing countries.

1. Introduction

The earth is currently enduring a period of unprecedented environmental change due to unsustainable anthropogenic activities in the recent centuries (Malhi, 2017; Chu and Karr, 2017; IPCC, 2022a, IPCC, 2022b). A number of researchers 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 massively contribute to carbon emissions and disruption of ecosystems (Montt et al., 2018; IPCC, 2022a, IPCC, 2022b; Labaran et al., 2022). The environmental effects of anthropogenic activities in geological timeframes suggests that many generations to come will be negatively affected by previous unsustainable anthropogenic processes (e.g. Gray-Cosgrove et al., 2015; Shende et al., 2015; Fletcher et al., 2024). Drawing on this, the need for scientific comprehension of the effects of anthropogenic activities on environmental sustainability has reached a critical level.

Wetlands are some of the ecosystems most affected by anthropogenic activities, especially in developing countries, where they are exploited for a plethora of purposes (e.g. Adeeyo et al., 2022). Extant research on wetlands reveals alarming levels of deterioration or disappearance due to unsustainable anthropogenic activities (e.g. Staunton et al., 2014, 2015). This research highlights 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 the world's 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., 2014; Ahidur, 2016; Mandishona and Knight, 2022). The deterioration or disappearance of wetland ecosystems is a major catastrophe for both human and non-human actors, because they play a number of critical roles necessary for environmental equilibrium. For example, wetlands are linked with the function of providing habitat to approximately 40% of the 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 of the loss (e.g. Staunton et al., 2014; Ballut-Dajud et al., 2022; Ali-Khani et al., 2023; Mangoro and Kubanza, 2023). This is inextricably linked to rapid urbanization and economic expansion, which necessitates a high demand for infrastructure. Although urbanization and economic expansion are a critical component of human processes, infrastructural development produces massive and heterogeneous volumes of construction and demolition waste (CDW), which pose a risk 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 growth 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 (see Fitchett, 2017; Mangoro and 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's population will reach 9.8 billion by 2050 and 11.2 billion by the 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 (United Nations Environmental Program – UNEP, 2023), from the current estimated population of 1.21 billion (O'neall, 2024). The realization of these estimations suggests imminent growth of construction activities and the related waste (CDW), and their associated effects on ecosystems (United Nations Environmental Program – UNEP, 2023).

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Drawing from the above, this study investigated the effects of anthropogenic activities on wetlands in Diepsloot and Tembisa, with a bias to 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, with a view to predict the state of wetlands in the study area by the year 2040 (e.g. Fantaye et al., 2017; Jombo and Adelabu, 2023). In view of this, it is clear that remote sensing can be an incredibly useful 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. In the following section, a critical synthesis of extant literature is provided with a view to understand the causes of wetland loss across the world.

2. Literature review

2.1. Accounting for global wetland loss

Wetlands are a critical ecological feature that have a number of 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 habitat and water to aquatic species (Gebresllassie et al., 2014; Zhu et al., 2023). By definition, wetlands are "Areas of marsh, fen, and peat land, 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 6 m" (Gebresllassie et al., 2014). 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.

A large body of literature across the world warns that the world has lost over 50% of the total number of wetlands combined since the beginning of the 20th century (Davidson, 2014; Hu et al., 2017). Hu et al. (2017) quantified the extent of global wetland loss per continent, and the results of the study indicated a grim spectre for 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 (Hu et al., 2017). 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; Sithirith, 2015; Hu et al., 2017; Zhu et al., 2023; Penfound and Vas, 2023). A study revealed that geographically isolated wetlands, which typically have dense vegetation cover, are at risk of dying out because of climate change (Zhu et al., 2023). In this study, it is argued that climate change can lead to loss of wetland vegetation cover, which could then 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 a reduction in the water content of wetlands, and their eventual loss (Zhu et al., 2023). The effects of climate change will continue to threaten the existence of wetlands across the world. Through the use of geographical information systems and remote sensing applications, a study indicated that by the year 2099, the effects of climate change will lower the wetland water table by approximately 26cm (Zhu et al., 2023). By nature, a wetland's water table is generally situated close to the surface, which means that a 26cm shrinkage will contribute to the eventual loss of more wetlands due to poor recharge of water.

While climate change is known to cause significant wetland loss, many of the threats to wetlands are inextricably linked to anthropogenic activities (Dallut-Bajudetal, 2022). Agriculture is the largest known cause for wetland loss across the world (Gebresllassie et al., 2014; OECD, 1996; Mandishona and Knight, 2022), accounting for about 25% of this loss (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 and Knight, 2022). For example, in the south western parts of Ethiopia, government and farmers are involved in 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 and Knight, 2022). The use of wetlands for agricultural purposes or other ecosystem services eventually leads to their disappearance, or the permanent disruption of their 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 a massive loss of wetlands. Research by Dallut-Bajudetal (2022) estimates that urbanization is responsible for 16.8% of global wetland loss. Urbanization is typified by development activities such as 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 increases surface run off. Ultimately, construction activities reduce wetland water recharge or their water retention capacity (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 China 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 situation of success and environmental deterioration.

Urbanization is a large cause of wetland deterioration as discussed above, but it has an additional effect of encouraging pollution in the event of poor environmental management systems. Some researchers associate increasing urbanization with wetland pollution, because population growth results in fast-paced production of construction waste, among other waste streams (e.g. Sithirith, 2015; Fitchett, 2017; Mangoro and Kubanza, 2023). However, cases of wetland pollution by urban waste also occur in developed countries. Staunton et al. (2014) documented cases of pollution through construction waste in the Republic of Ireland, which led significant alteration or even the total disappearance of wetland ecosystems. In addition to pollution from urbanization, there are a number of cases where urban wetlands are connected to the sewerage system. This practice diminishes the ability of wetlands to function optimally, due to 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 policies, together with weak institutions, heightens the vulnerability of wetlands because this combination generates confusion within the associated sectors. For instance, in Cambodia and Ethiopia, the 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 lack of capacity for wetlands management. Cases of shortage of manpower, funding and technology for sustainable wetlands conservation abound in developing countries (Gebresllassie et al., 2014). Lack of manpower emanates from the absence of training programmes for wetlands conservation or management at institutions of higher learning (Gebresllassie et al., 2014).

2.2. Accounting for wetland loss in South Africa

Wetland loss is a phenomenon in South Africa which emerged several decades ago. Existing aquatic research in South Africa reveals that wetland loss rose from 45% in the 1980s to about 65% in the 1990s (Whyte and Shepherd, 1999), while other research records it at almost 50% in the last two decades (Von Staden, 2013). More recent research has established that there are about 300 000 wetland ecosystems remaining in South Africa (Adeeyo et al., 2022). It is argued that of this number, 48% are at high risk of further disruption, while 12% are now endangered, and 5% are prone to human exploitation, and only 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 and Shepherd, 1999; Rivers-Moore and Cowden, 2012; Adeeyo et al., 2022).

One of the major anthropogenic activities accounting for wetland loss in South Africa is mining operations. For example, research in some parts of South Africa such as Mpumalanga, suggests that mining activities (e.g. for coal) have disrupted or destroyed vast tracts of wetland areas (Van Vuuren, 2014; Water Research Commission, 2016). This is because wetlands are generally situated in low-lying areas where miners prefer to undertake open-cast mining due to its relatively low cost in comparison to other mining methods (Van Vuuren, 2014; Water Research Commission, 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 Research Commission, 2016). However, mining activities in South Africa have also been linked with wetland loss through deposition of polluted water, which ultimately affects the integrity of these ecosystems and the related biodiversity (e.g. 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). Species like velvet mesquite (*Prosopis velutina)* have a significant negative impact on wetlands, associated biodiversity, recharge ability, and on human livelihoods (Solitude Lake Management). Similarly, some researchers argue that wattle (silver, long weaved and black wattle) uses excessive amounts of water, resulting in disruption of wetland ecosystem functionality (AgriOrbit, 2020). Therefore, in the event that 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 a massive threat to wetlands in South Africa, other anthropogenic activities like agriculture are also a leading cause of loss (Grundling, 2011; Sinthumule and Netshisaulu, 2022). For instance, crop farming, plantations, and irrigation schemes cause environmental deterioration, and a dwindling of the wetlands in areas of South Africa such as KwaZulu-Natal and Limpopo (Grundling, 2011; Sinthumule and Netshisaulu, 2022). Furthermore, communities in rural areas have understood that some wetland ecosystems have rich soils that could provide adequate nutrients for 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 the ability of wetlands to provide ecosystem services such as recharge of rivers, or provision of habitat to certain marine species. This problem grows in significance, considering that only 11% of different wetland types in South Africa are protected by the Ramsar Convention (Adeeyo et al., 2022). Furthermore, research by Skowno et al. (2018) indicates that only 6% of wetlands located in inland areas are protected, and these are found in conservation areas such as parks or reserves. This is a massive problem, because due to increasing droughts, more wetlands are likely to be targeted for subsistence farming in South Africa.

In addition to issues discussed above, wetland loss in South Africa is also a result of construction-related activities (Mlambo, 2018; Adeeyo et al., 2022; Sinthumule and Netshisaulu, 2022). Due to a rise in population in South African cities, there is commensurate rise in 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, Gauteng (Kings, 2018). This construction resulted in permanent loss of an extensive wetland. 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 a total wetland loss and a major disruption of their ability to perform ecosystems services (Collins, 2006).

While there is extensive literature on the current state of conservation of wetlands in South Africa, as discussed above, there is a general scarcity of scientific knowledge on the potential impacts of anthropogenic activities, such as illegal dumping, on the ecosystems in decades to come. Land use planning is a critical component of urban planning and governance, especially in Sub-Saharan Africa where much of the future population growth is poised to occur. Therefore, comprehensive scientific knowledge on urban ecosystems such as wetlands is required to inform urban planning processes for informed decision-making. Another gap in current literature on wetlands is that most studies typically focus on individual sites due to the perceived associated costs of conducting assessments on multiple sites (see Rivers-Moore and Cowden, 2012). This approach to wetlands studies is useful but provides only localised scientific knowledge, which cannot necessarily be applied to other contexts, and which cannot inform urban environmental governance adequately. In this study, an attempt is made to narrow this gap by focusing on land use and land cover change trends around wetland sites in Diepsloot and Tembisa informal areas, in order to determine the long-term impacts of anthropogenic activities such as illegal dumping. The significance of this study lies in the fact that it provides data and pointers crucial for mitigation of wetland loss before it happens.

3. Materials and methods

3.1. Study area

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, at an average altitude of between 1280 and 1660m (Mucina and Rutherford, 2006). The settlements are located on an extensive catchment area formed by Jukskei and Kaalspruit Rivers, their tributaries, and a network of wetlands (Fig. 1). In terms of geology, the study areas are both situated in the Savana Egoli Archaean granite and gneiss landscape, with coarsely grained sandy soils which have few nutrients (Mucina and Rutherford, 2006). Generally, the landscape is moderately undulating, with low hills in both areas, which is crucial for river drainage (see Mucina and Rutherford, 2006). In terms of vegetation, the virgin areas consist of grassland dominated by *Hyparrhenia hirta*, with occasional woody species on rocky outcrops. The general area falls within the summer rainfall region, with dry winters. Additionally, the rainfall ranges between 620 and 800mm per annum (Mucina and Rutherford, 2006), contributing to the

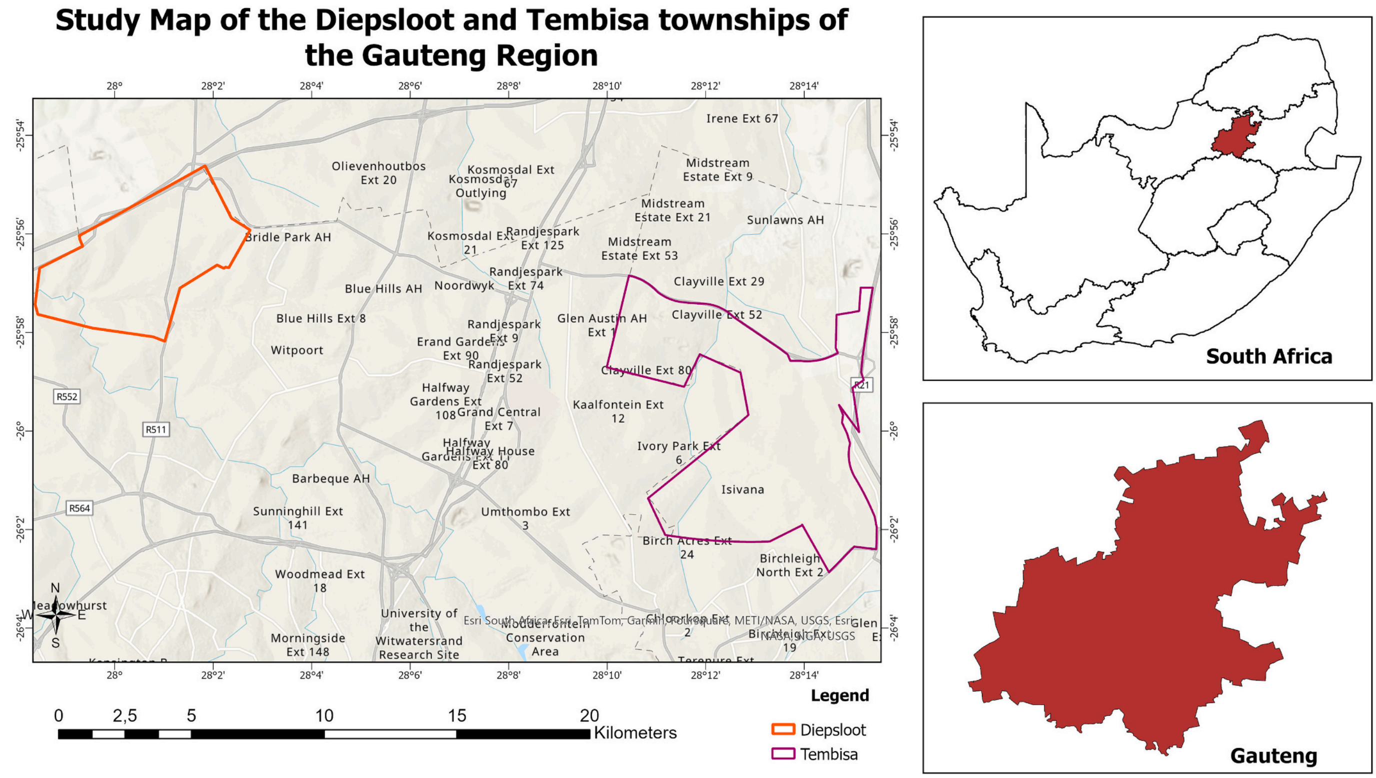

Fig. 1. Study Area and the surrounding places.

continuous flow of rivers in the area. However, due to the increasing effects of climate change on rainfall patterns around the world, this may change.

In terms of the built environment, the two settlements have a dense concentration of dwellings, on both authorised municipal land, and on unauthorised areas, such as flood plains of the Jukskei and Kaalspruit Rivers (e.g. Fitchett, 2017; Mashazi et al., 2019; Mangoro and Kubanza, 2023). Due to shortages of housing units and the rising cost of living in South Africa, both Diepsloot and Tembisa have transformed into mixed settlements of formal and informal areas, especially in the last 20 years (Marutlulle, 2017; Mangoro and Kubanza, 2023).

Wetlands in the region and their riparian zones form habitat for a number of critical wildlife species, which include the near endangered African Giant Bullfrog (*Pyxicephalus adspersus*), and the grass owl (*Tyto longimembris*) (Yetman and Ferguson, 2011; Mangoro and 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 habitats for various wildlife species. Specifically, there is intense illegal dumping of household waste (frequently remediated) 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 study area in current and future contexts.

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 paper uses the period from the years 2000–2020 on ten-year intervals as the benchmark. This is because population growth and rapid infrastructural development in the area transpired during this period. Satellite imagery of the study area in this twenty-year period 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 of time in the future. In this paper, a twenty-year period from 2020 to 2040 was selected.

To measure topographic events from the years 2000–2020 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, on a 16-day repetitive sequence, which is referenced as the World Reference System-2 (United States Geological Survey USGS, 2018).

In addition to the above, 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 (United States Geological Survey USGS, 2013; Dibs et al., 2023).

Radiometric calibration was applied to each image, then atmospheric correction using 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 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.

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 December 20, 2023. The temporal data was used to evaluate 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, 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.

3.4. Image classification

For the LULCC classification process, 4 classes were selected for Diepsloot (namely wetlands, vegetation, bare land and built-up areas), 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 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).

3.5. Accuracy assessment

Classification accuracy is the most critical feature to assess the reliability of the final map outputs. It encompasses statistical estimates obtainable from the classification output and an independent reference dataset so as 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 are estimated 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).

3.6. Change detection

In this study, change detection was executed using the change detection statistics tool in ENVI 5.4 (e.g. Haque and Bazak, 2017; Juliev et al., 2019). This was done to examine the shifts in the various LULCC classes, particularly the wetland areas. The outcome of the examination were three maps, for 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 also 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.

3.7. 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 was used. 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 is superior and more robust in predicting LULCC in comparison to other models, such as Marcov and linear regression (Abbas et al., 2021; Rahman et al., 2017). For the future simulations. The 30 $\times$ 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 also 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. Results and analysis

4.1. 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, built up and cultivated areas and bare land were classified. Fig. 2 provides an LULCC map tracking topographical changes between year 2000 and 2020.

In Fig. 2, a dramatic increase in built up areas can be observed in Diepsloot, which suggests rapid construction processes to accommodate an increasing population. 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 rapid 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 Fig. 2. The LULCC transpiring in Diepsloot between 2000 and 2020 are graphically and quantitatively illustrated in Fig. 3 and Table 1.

Massive changes in LULCC in Diepsloot are clearly noticeable in Fig. 3. To provide a full picture of these changes, Table 1 illustrates the area of land covered by the four selected feature classes in this study. It can be observed that the area covered by wetlands diminished from 368.82 ha in 2000 to 56.25 ha in 2010, and 18.9 ha in 2020, suggesting an overall percentage drop from 14.58% to 2.22% (Table 1). Furthermore, changes can be seen in vegetation cover, which dropped from approximately 1413.09 ha in 2000 to 786.78 in 2020, representing a drop from about 55.85% to 31.09% currently (Table 1).

From Table 1, changes in area covered can also be observed with built-up areas, which increased from 465.93 ha in 2000 to 990.81 ha in 2020, representing an upward trend of 18.41%–39.16% (Table 2.).

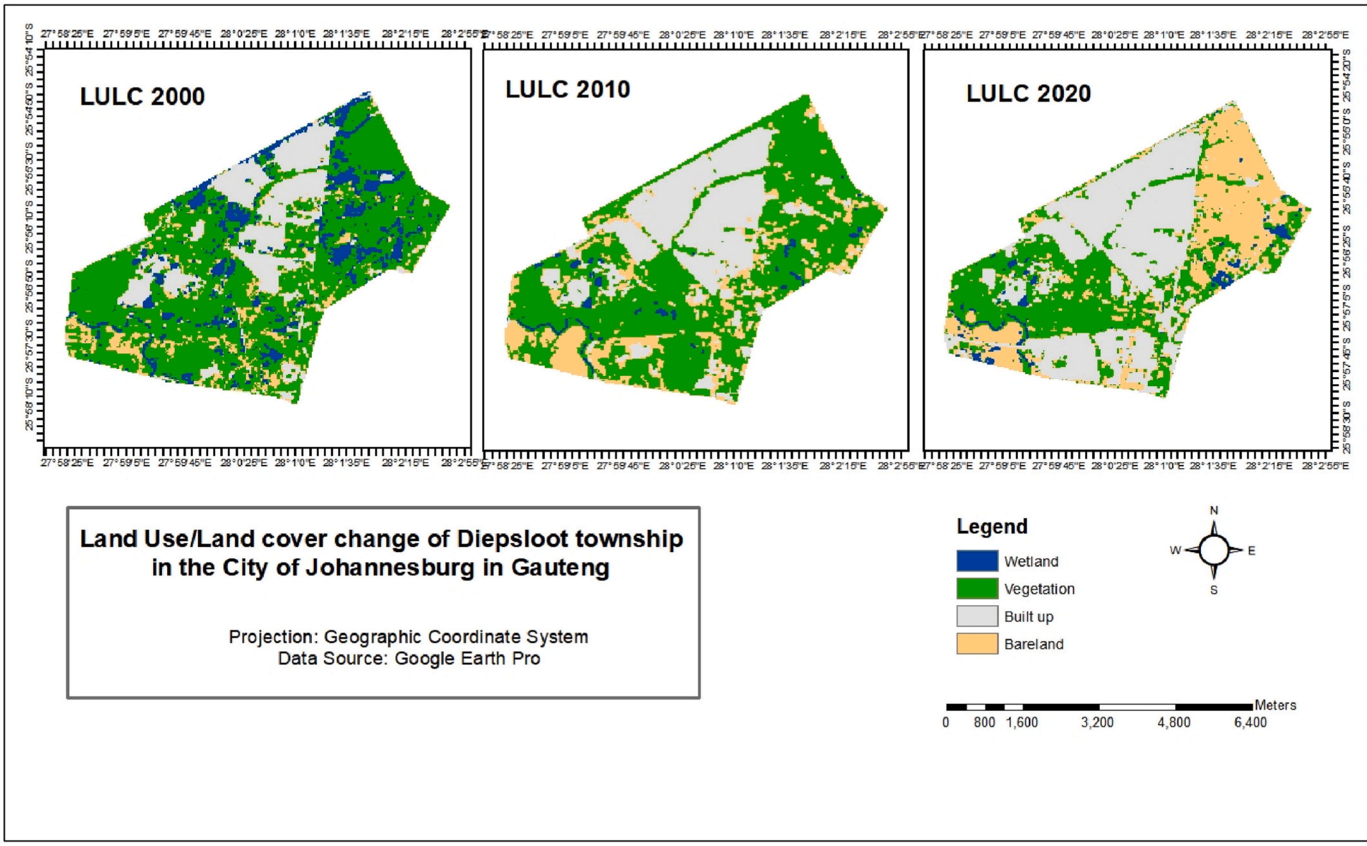

Fig. 2. LULCC trends in Diepsloot between 2000 and 2020.
Source: Researcher

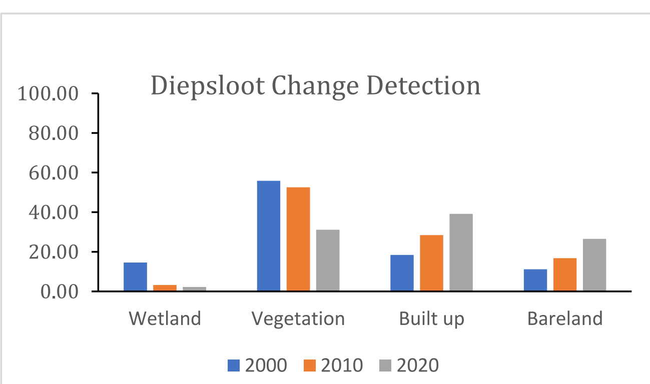

Fig. 3. Summary of land use and land cover change in diepsloot.
Source: Researcher

Table 1
Trends in area covered by selected features.

Diepsloot (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
	2530,35	2530,35	2530,35

Lastly, the area covered by bare land demonstrably increased from 282.51 ha in 2000 to 670.9 ha in 2020 – a change from 11.16% to 26.51% at present, suggesting massive vegetation clearance to pave the way for human activities in future.

4.2. Study area 2: Tembisa township, Ekurhuleni Municipality

The impact of anthropogenic processes in LULCC in Tembisa is clearly noticeable in study area 2 (Fig. 4). Firstly, there is a sharp increase in built-up 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 (e.g.

Table 2
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

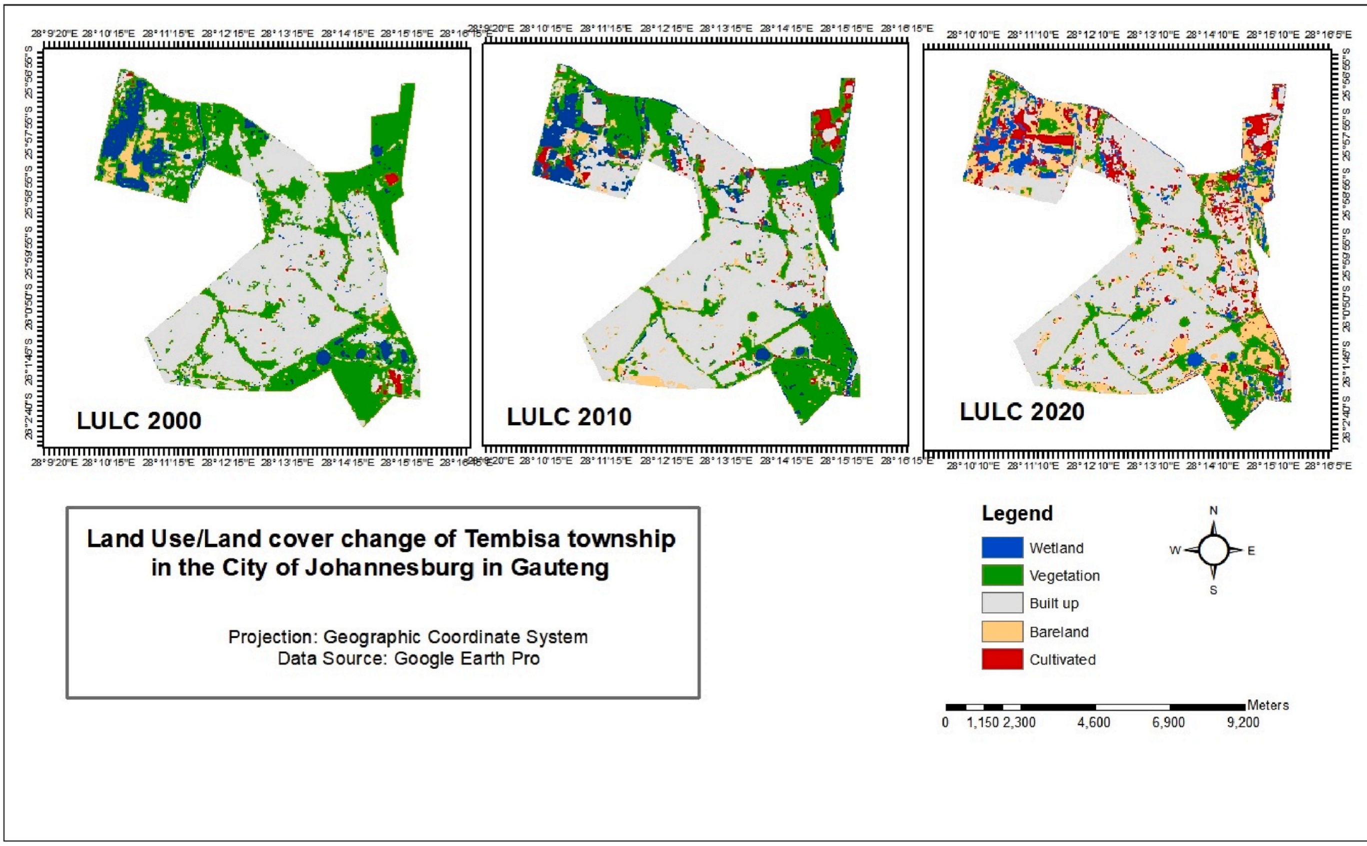

Fig. 4. LULCC trends in Tembisa between 2000 and 2020.

Ekurhuleni Metropolitan Municipality, 2008).

Fig. 5 captures the trends in LULCC in Tembisa as described above, and a decrease in wetland area can be observed. Table 3 shows that wetland areas decreased from 468 ha in 2000 to 384.12 and 227.88 in 2020, representing a drop from 8.65% to 4.21% in 2020. Furthermore, vegetation cover decreased from 2119.59 ha in 2000 to 1456.56 in 2010 and 227.88 in 2020 (Table 3), suggesting a drop from 39.17% to 16.93% (Table 4). By contrast, the built-up area increased from the original area covered from 2475.27 ha in 2000–2573.73 in 2010, and 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 programme. Finally, there is an increase in land cultivation for agriculture from 58.41 ha in 2000 to 203.85 in 2010, and

Table 3
Trends in area covered by selected features.

Tembisa (ha)			
	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
	5411,16	4868,01	5193,45

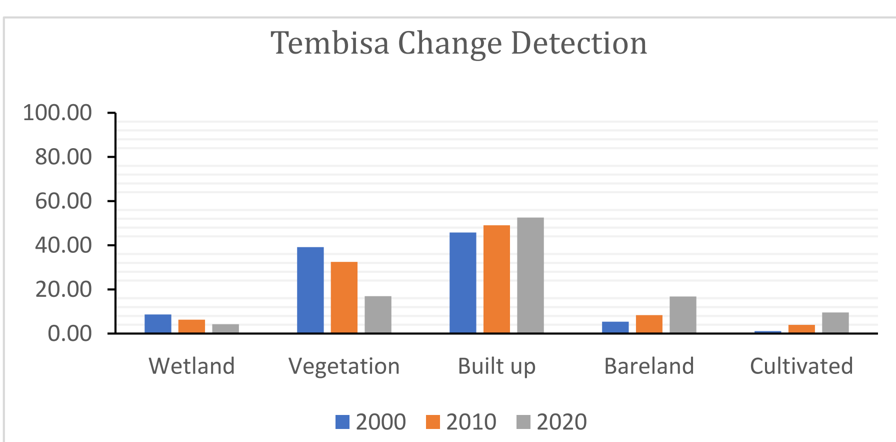

Fig. 5. Summary of land use and land cover change in Tembisa.

Table 4
Percentage 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

517.77 ha in 2020 (Table 3), representing an increase from 1.08% to 9.53% at present (Table 4).

The above statistics and illustrations 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 above statistical trends were used to predict future LULCC in the study area up to the year 2040.

4.3. 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. 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, Figs. 6 and 7 provides an illustration of potential environmental events by year 2040 (see Fig. 8).

In Figs. 6 and 7, 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 Fig. 6, it can be observed that by 2040, only 9.54 ha of wetland cover will remain in Diepsloot, and 107.01 ha in Tembisa (Table 5).

An increase in built-up areas is inevitable based on the trends in human population between 2000 and 2020. Furthermore, due to increased cost of urban housing in South Africa, more people will be put on the housing waiting list, who often wait decades to eventually get a house. This means that a significant part of the population will flock to areas like Diepsloot and Tembisa to build low-cost housing shacks, usually on undesignated locations such as wetlands. To generate land for illegal construction (typically shacks), wetlands are targeted for infilling, especially with construction and demolition waste. The use of construction waste for infilling wetlands has strong precedence in both areas. Fig. 9 provides further evidence.

5. Discussion

Land Use and Land Cover Changes (LULCC) in the study areas from year 2000–2020 indicates some events consistent with overconsumption 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 finding is consistent with observations of changes due to unsustainable anthropogenic activities in South Africa from other studies (e.g. Mclean et al., 2016; Zungu et al., 2020; Mangoro and Kubanza, 2023). 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 case studies.

What is particularly important to note is that construction over wetlands in the study area is a component of a much larger social and environmental injustice problem in South African cities. This arises from

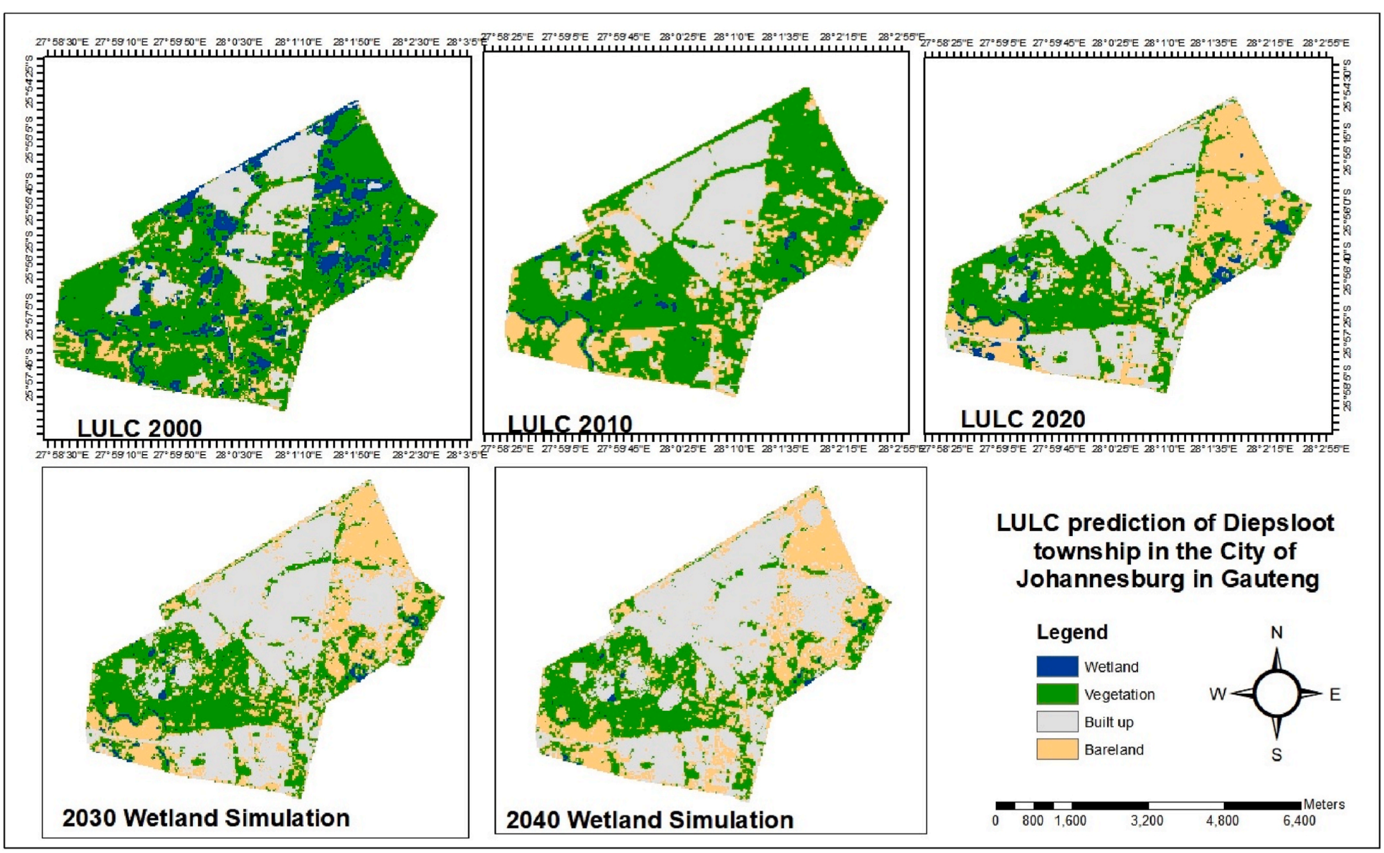

Fig. 6. Simulation land use and land cover change in Diepsloot by 2040.

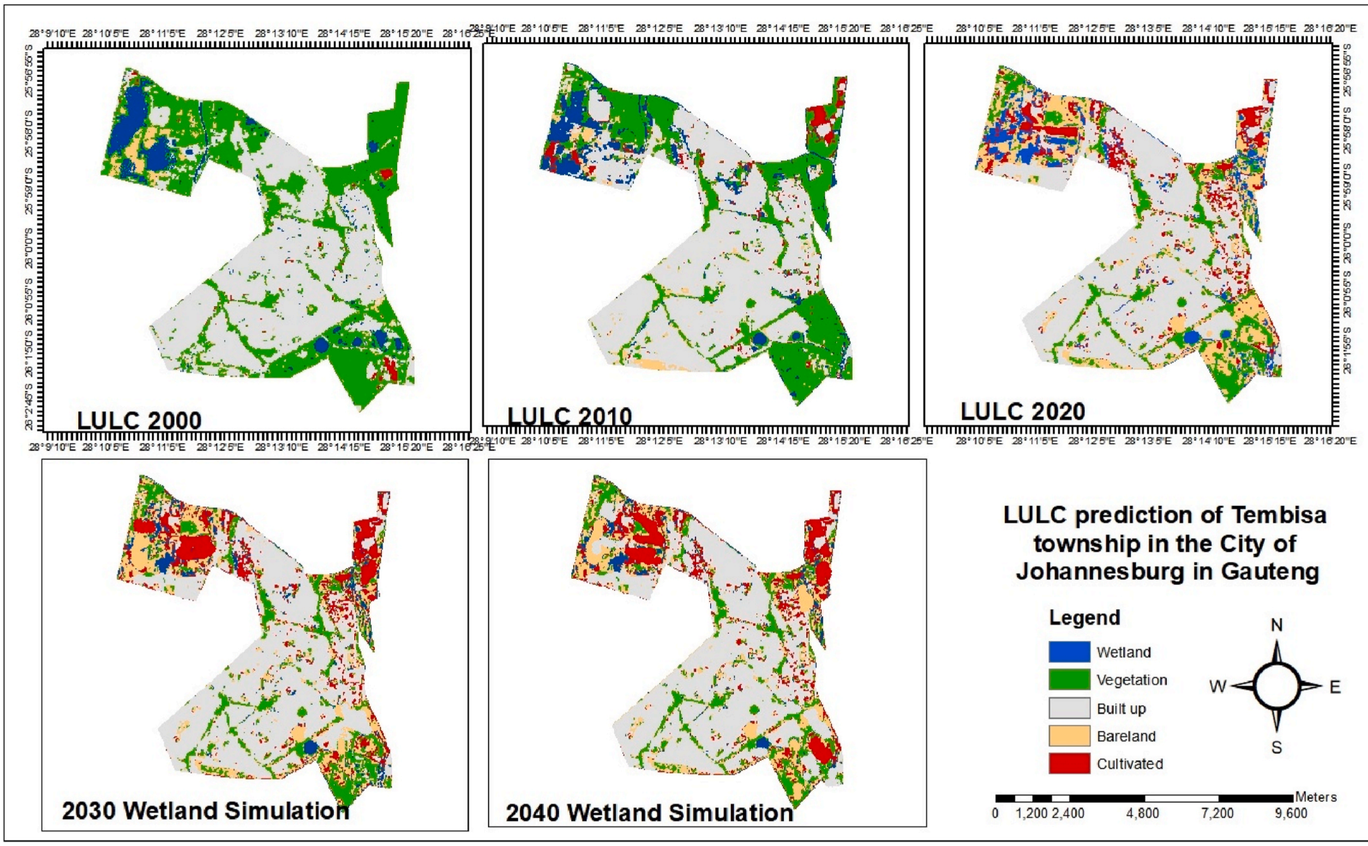

Fig. 7. Simulation land use and land cover change in Tembisa by 2040.

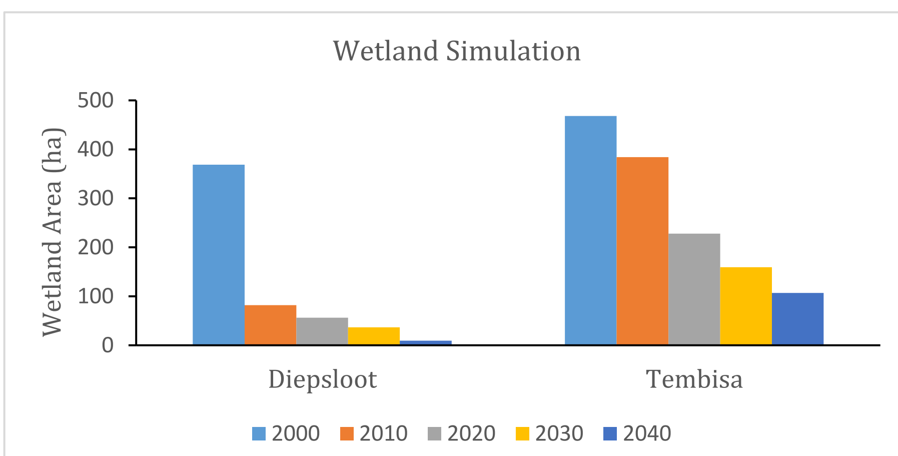

Fig. 8. Graphical illustration of Land Use and Land Cover Change in Diepsloot and Tembisa by 2040.

Table 5
Simulation of land use and land cover change 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

the illegal exportation of CDW from high income areas in the northern areas of Johannesburg into study area for infilling of wetlands (e.g. Styger, 2019; Bega, 2018). It is critical to note that much of the licit construction processes in Johannesburg in the last 20 years occurred in the high-income suburban areas in the northern areas. However, poor municipal land use planning and shortage of landfills in these areas (e.g. Simelane, 2017), motivates environmental crimes such as disposal of CDW in wetlands around Diepsloot and Tembisa (Bega, 2018; Mangoro and Kubanza, 2023). However, the rise of construction-related environmental problems in Johannesburg goes beyond shortage of landfills and poor land use planning. Proliferation of the illegal land grabs and emergence of a powerful 'construction mafia' in South Africa (e.g. Nyangiwe et al., 2023), has further aided the infilling of wetlands with CDW to generate dry land for illegal construction in low-income areas. Similar trends were observed in several studies across South African provinces such as Gauteng, Western Cape and KwaZulu-Natal, where wetland areas are targeted for dumping to generate dry ground for illicit

Fig. 9. Construction and demolition waste throttling wetlands in Diepsloot and Tembisa.

construction (e.g. Kings, 2013; Moagi, 2018; Ngcuka, 2021). Extant literature suggests that poor CDW management in South Africa has occurred for an extended period to date, and findings of this study further confirm this.

Using urban land use trends from 2000 to 2020, this study also conducted a predictive analysis of LULCC in the study area, to investigate the potential state of wetlands by 2040. Based on these trends, a quantitative analysis, using remote sensing techniques, in this study found that wetlands in both Diepsloot and Tembisa will likely deteriorate further to the point of near total disappearance, due to illegal dumping of CDW. Disappearance of wetlands due to infilling with CDW is recorded in some parts of the world (e.g. Staunton et al., 2014, 2015). However, in some cases such as in the Republic of Ireland, infilling of wetlands with CDW is often permitted by the law (Staunton et al., 2014), marking a remarkable distinction with the case study of South Africa. Ultimately, dumping in wetlands causes a number of negative effects on the environment, including loss of habitat, loss of water sources, disruption of the carbon capture function, and loss of species among others. This has massive ramifications on species dependent on wetlands, such as bullfrogs and fish, among others. Additionally, humanity will also be affected because wetlands provide ecosystem services such as a water supply, which are critical in a water-scarce region like South Africa, and provision of space for cultural activities (e.g. Mandishona and 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. In this case, however, cultivation largely disrupts the organic function of wetlands rather than completely consuming them, which would lead to their total disappearance. Furthermore, although CDW is the largest threat to wetlands in Diepsloot and Tembisa (Gauteng), household waste from the case study areas also presents threats (see Fitchett, 2017; Mangoro and Kubanza, 2023). Additionally, it is important to note that there are often some clean-up or rehabilitation programmes by some non-governmental organizations (e.g. Mosina, 2016; Fourways Review, 2017; Kirk, 2017). Clean-up programmes on wetlands in the study areas specifically target household waste because of relative ease to manipulate and move it. Heavy and ubiquitous waste, such as CDW, is deliberately ignored because it requires massive capital investment and other logistical arrangements.

It is however important to note that while the predictive analysis informing this study suggests a gloomy future for wetlands in the study area, implementation of mitigation measures by the responsible parties such as local and provincial government could result in restoration of wetlands to full organic function. For example, the South African government started the 'Working for Wetlands' programme that seeks to rehabilitate and conserve wetlands under anthropogenic threats (Kotze et al., 2019; DEFF, 2024). Through this programme, the South African government has invested approximately US$65.8 million or R1.2 billion between 2004 and 2019 to rehabilitate 1500 wetlands throughout the country (DEFF, 2024). This wetland rehabilitation programme provides hope that wetlands such as those in the study area could be rehabilitated to avoid the projections indicated in this study. However, the debilitating economic conditions in South Africa (e.g. Mbandlwa, 2023), supported by extant literature on the subject suggests that this is unlikely to occur. Restoration of wetlands in South Africa is hampered by the severe shortage of funds (e.g. Kotze et al., 2019). Additionally, the 'Working for Wetlands' programme is severely permeated with methodological shortfalls. For instance, the rehabilitation programme is achieved through erosion control, bio-engineering, revegetation, clearance of invasive species or construction of new wetlands (DEFF, 2024). While these measures appear to be methodologically relevant and effective, they fall short of measures to remediate infilled wetlands. Furthermore, these measures totally ignore procedures to handle buildings constructed on infilled wetlands such as those in the study area. Therefore, while wetland degradation is reversible, the likelihood of this scenario in South Africa at large is low, considering the reasons given above. This means that thousands of wetlands will remain covered in CDW and the built environment across the major cities. Furthermore, this lack of procedures suggests that more infilling of wetlands will continue in the urban areas of South Africa, and this further supports the findings of this study.

6. Conclusion

This study provided a comprehensive analysis of LULCC in Diepsloot and Tembisa in the Gauteng Province of South Africa between the years 2000 and 2020. It is found that anthropogenic activities, which includes mass scale illegal dumping of CDW, and construction activities, induce massive environmental damage, particularly in the case of wetlands. Through predictive analyses based on illegal dumping trends from year 2000–2020, it was found that continuation of similar trends between 2020 and 2040 would lead to near-total disappearance of wetlands in the study area. It is argued that although pro-environmental initiatives such as wetland rehabilitation could challenge the findings of this investigation, this scenario is unlikely because South Africa has an extended history of overlooking wetlands that are not part of the Ramsar list. Additionally, the existing wetlands rehabilitation programme is severely underfunded, and this is compounded by the associated weak methods, as discussed in the earlier sections. The weak methodological approaches associated with the 'Working for Wetlands' programme spearheaded by the South African government means that effective wetland conservation or protection from anthropogenic threats remains idealistic and unachievable.

While this investigation successfully provided critical insights into the potential future of wetlands in the Gauteng Province, it had some weaknesses that need attention in future similar studies. First, the study could have benefitted from a hybrid methodology of remote sensing techniques and a participatory action research strategy, based on interviews with environmental epistemic communities. This would have provided critical insights on why urban wetlands are rapidly targeted for environmental crimes such as illegal dumping of CDW. Secondly, the study did not provide a future flood risk analysis of the study area. Flood risk analyses is critical for purposes of urban planning, and together with the findings of the current study, this would have been critical in the formulation urban waste management strategies. However, the findings of this study remain critical in environmental research in developing countries, particularly in Sub-Saharan Africa, as they can be used in urban waste, environmental and health planning considerations.

In conclusion, a number of recommendations are made to reduce anthropogenic pressure on wetlands, especially those situated in the low-income urban areas. First, there is need for wetland delineation and construction of barriers to discourage direct deposition of construction and demolition waste and other waste streams. Currently, communities in the case studies have easy access to wetlands, and due to the lack of environmental education, and absence of physical barriers, wetland dumping remains a widespread problem. Based on this, it is critical that pro-environmental initiatives are introduced, especially in low-income areas. This is a critical recommendation, because wetlands in the study area are located close to residential areas, and are therefore easily accessible for environmental crimes such as illegal dumping, as illustrated in the findings of this study. In addition, there is need for massive wetland rehabilitation programmes in the study area, because construction waste is voluminous and heavy, and therefore cannot be eroded easily. As this study has found, this means that with repeated deposition over time, wetlands will eventually disappear. Introduction of rehabilitation programmes should be accompanied with a robust methodological shift in the 'Working for Wetlands' programme, which has so far produced limited impact on wetland conservation across South Africa. Finally, there is need for a multistakeholder environmental management approach, where players such as NGOs, local municipalities, private companies, and local communities among others can collaborate in environmental management programmes. A collaborative approach is critical for environmental governance and management because it involves the sharing of resources, information, and skills required to achieve environmental sustainability. Ultimately, the above recommendations are critical because they lead to restoration of critical ecosystems in a water-scarce region like South Africa.

CRediT authorship contribution statement

Ngonidzashe Mangoro: Writing – original draft, Formal analysis, Conceptualization. **Nzalalemba Serge Kubanza:** Supervision, Project administration, Formal analysis. **Mulala Danny Simatele:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ngonidzashe Mangoro reports equipment, drugs, or supplies was provided by FreshNGO & Gecko - Greater Kyalami Conservancy. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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