A GIS framework for the integrated conceptualisation, analysis and visualisation of Gauteng's complex historic and contemporary post-mining urban landscape

Doctor of Philosophy

By

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DECLARATION

I, Samkelisiwe N. Khanyile, declare that this thesis is my own work. It is being submitted for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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(Signature of candidate)

20th day of November 20 23 at Johannesburg

ABSTRACT

This research study applies assemblage theory as a philosophical lens. It proposes a framework for integrating contemporary and historical landscape characteristics of post-mining and urban landscapes for an integrated conceptualisation, mapping, and analysis of Gauteng, South Africa. The study utilises a mixed methods approach, incorporating spatial and non-spatial (literature and survey) data of varying formats to identify landscape characteristics. Additionally, it applies three multicriteria decision analysis (MCDA) and GIS mapping techniques, employing a simplified rationale to keep its complexity low.

Descriptive and inferential statistics were used to analyse the quantitative data, while the qualitative data was analysed using a thematic analysis. The literature and survey analysis findings were used to inform the development of a framework demonstrating the integration of Gauteng's post-mining and urban landscape characteristics using a fuzzy overlay, weighted overlay and random forest classification, along with an accuracy assessment of the mapped results. Based on the proposed framework, the mapped results' performance was evaluated through four methods: confusion error matrix, cross-evaluation, areal coverage comparison, and an image differencing assessment.

The literature and survey analysis findings, used to inform the framework, reveal that the two landscapes consist of an assemblage of characteristics and highlight differences in the characterisation of post-mining and urban landscapes. Distinctions were also apparent between literature-derived characteristics and those identified from local experts. The local expert-derived characteristics demonstrate context-specific characteristics of Gauteng's post-mining and urban landscape. At the same time, those based on the literature emphasise a more distinct and separate portrayal of post-mining and urban landscape characteristics (pages 115-116). The characteristics identified from local experts were less conservative (pages 117-118). They included urban-related characteristics in the description of post-mining landscapes and mining-related characteristics in the description of urban landscapes, presenting some similarities in the characterisation of these two landscapes in Gauteng. Moreover, the findings from local experts also revealed that literature and other written or mapped work informed most definitions of post-mining and urban landscapes.

The framework for integrating landscape characteristics (pages 121-123) was spatially represented through the three mapping methods, visually demonstrating several findings providing insight into the Gauteng landscape's uniqueness. First, it demonstrates that the differences in the characterisation of these landscapes also impact how they are spatially represented. The maps of post-mining and urban landscape characteristics based on the literature presented a similar pattern to the traditional mapping of mining and urban landscapes in Gauteng. These mapping techniques show the highest values across the mining belt and at the province's core. These findings highlight the influence of literature on the

representation of these two landscapes, which is consistent with local experts' reports. In all three mapping methods, the maps generated from local expert characterisations of post-mining and urban landscapes presented a larger spatial footprint than those based on literature-derived characteristics. This distinction was attributed to incorporating additional post-mining and urban landscape characteristics in the maps based on expert input and applying the three mapping techniques - using representation methods not commonly used in mapping these landscapes.

Second, the integrated maps of post-mining and urban landscape characteristics suggested a variance in the presence of post-mining and urban landscape characteristics across the province in the maps generated using fuzzy and weighted overlay techniques. This indicates that some parts of the province have a higher or lower presence of post-mining or urban characteristics (pages 125-132). These findings were visible in the maps generated from literature and local experts, indicating the diversity of both landscapes and the co-existence of post-mining and urban landscape characteristics in the local expert maps. This implies an intricate relationship between these landscapes, challenging the idea of them being strictly separate, as indicated in maps presenting characteristics identified from the literature. Furthermore, a closer inspection of the areas showing the intersection between post-mining and urban landscape characteristics also points towards the porosity of boundaries of these two landscapes and a level of spatial overlap, organisation and arrangement, which are prevalent at varying levels (pages 164-168).

Third, the maps generated using literature-derived characteristics achieved higher accuracy scores, attributed to using reference data traditionally used to map the two landscapes under investigation. This reference data only comprised classes that characterised the physical mining and urban classes, consistent with those identified in the literature. Consequently, it lacked additional factors characterising the post-mining and urban landscape identified from local experts. The fuzzy overlay maps informed by literature demonstrated an accuracy exceeding 70% for post-mining and urban landscape characteristics. In comparison, those reported by local experts scored 64. The weighted overlay and random forest classification resulted in accuracy rates exceeding 50% for post-mining landscape characteristics maps, regardless of whether literature or expert-derived characteristics were used.

Additionally, urban landscape characteristics maps achieved an accuracy of over 76%, regardless of the characteristics used to inform the mapping. These findings were attributed to the different mapping techniques employed, with fuzzy and weighted overlay using a gradual range scale, while random forest classification employed a binary scale. This highlights how different mapping methods affect the representation of space. Additionally, it demonstrates the versatility of these mapping techniques in mapping complex spaces such as post-mining and urban landscapes. In this study, the fuzzy overlay accuracies exceeded 60% for all maps and emerged as the most suitable choice for integrating landscape characteristics due to its ability to represent blurred and porous boundaries between Gauteng's post-mining and urban landscapes.

In conclusion, the study challenges the notion of post-mining and urban landscapes as distinct landscapes, emphasising the importance of considering the varying levels of spatial intersection between these two landscapes. With the proposed framework and the alternative representation of these landscapes, including contextual information, this research provides insights into new conceptualisations of urban, post-mining landscapes and mineralised urbanisations as assemblages of different landscapes and characteristics with porous boundaries. This enables a better understanding of Gauteng's post-mining and urban landscapes, which could benefit the representation, communication and management of these landscapes.

Recognising the potential applications and limitations of frameworks such as the one developed for this study, the high-level recommendation arising from this study suggests a need for ongoing research into the contextual representation of landscapes and their characteristics. This can be achieved by incorporating input from communities, conducting research on quantifying intangible landscape characteristics and developing tools that facilitate the automation and alignment of such data with development plans.

DEDICATION

Dedicated to my mother, Mrs Sindisiwe Nomvula Khanyile (nee Mabaso), who always had a vision for me to attain the highest education qualification.

Ngyabonga kaMabaso, Mntungwa, Mbulazi, Mzilikazi kaMashobane, ngithi kuwe nawe awuncinyana!

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I would like to thank my supervisors. Dr **Stefania Merlo**, for her support and mentorship over the past nine years, has been invaluable. Prof. **Clare Kelso**, Prof. **Amanda Esterhuysen**, and Dr **Laven Naidoo,** thank you for getting me over the finish line. Their emotional support and academic guidance went a long way in helping me complete this study.

I would also like to thank my employer, the Gauteng City-Region Observatory (GCRO), for their support, allowing me the time and space to pursue my research interests, and generous study leave policy.

Lastly, I would like to thank my family, partner, friends and my entire' support village' for their encouragement, confidence and patience with me during periods of stress and for believing in me when I had little motivation.

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Full name
2D	Two-dimensional
3D	Three-dimensional
AHP	Analytical Hierarchy Process
AMD	Acid Mine Drainage
CER	Centre for Environmental Research
CGS	Council for Geosciences
CoEMM	City of Ekurhuleni Metropolitan Municipality
CoJ	City of Johannesburg Metropolitan Municipality
CoMSA	Chamber of Mines South Africa
CoT	City of Tshwane Metropolitan Municipality
CSIR	Centre for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DMR	Department of Mineral Resources
DWA	Department of Water Affairs
ESRI	Environmental Systems Research Institute
GCR	Gauteng City-Region
GCRO	Gauteng City-Region Observatory
GDARD	Gauteng Department of Agriculture and Rural Development
GIS	Geographic Information Systems
GPG	Gauteng Provincial Government
GTI	GeoTerra Image
LCA	Landscapes characteristics assessments
MCDA	Multicriteria decision analysis
MCDM	Multicriteria decision-making
MPRDA	Mineral and Petroleum Resources Development Act
MRAs	Mine Residue Areas
OECD	Organisation for Economic Co-operation and Development
OOB	Out-of-Bag
PGIS	Participatory Geographic Information Systems
RF	Random forest classification
SA	South Africa

SAEOR	South African Environmental Outlook Report
SDF	Spatial Development Framework
STATS SA	Statistics South Africa
STEPP	Strategic Tool for integrating Environmental aspects in Planning Procedure
UNDP	United Nations Development Programme

CHAPTER ONE: INTRODUCTION

1.1. BACKGROUND TO THE STUDY

The discovery of gold along the Witwatersrand mining basin in 1886 made Gauteng Province a significant South African and global mining region (Crush, 1986; Cammarck, 1990; Phillips, 2013). Since then, the mining activities of the Witwatersrand have been the catalyst for sustaining the economy and infrastructure of the country (Cowey, 1994), making the Gauteng province the country's economic backbone (Bredenkamp et al., 2006). Over the years, mining has fuelled rapid urbanisation and infrastructural development (Harrison and Zack, 2012). As such, Gauteng is the fastest urbanising province in South Africa and the rest of the African continent (Harrison, 2007; StatsSA, 2011). However, this urban landscape is characterised by prominent remnants of mining, mostly a post-mining physical landscape characterised by mine waste that has significantly influenced urban development trajectories.

Gauteng mirrors many other urban spaces, which rose to prominence with the discovery of minerals and the commencement of mining and other extractive industries. Bryceson and MacKinnon (2012) call such urban spaces' mineralised urbanisation', depicting "the influence of mineral production cycles and commodity chains on urban growth and settlement patterns at a local, regional and national level" (2012: 514). These mineralised urbanisations result from mining booms and mining-led migration to certain places, which have, over time, left lasting implications for national economies and urban development trajectories of certain mining areas (Emuze and Hauptfleisch, 2014).

This is particularly interesting as the development of many cities and towns globally is due to the discovery of minerals. For example, in America, San Francisco developed from the Californian gold rush (Walker, 2001; Brands, 2002 in Bryceson and MacKinnon, 2012). Many African cities, such as Accra in Ghana, have developed due to mineral discoveries. Johannesburg and Kimberly in South Africa also arose from discovering gold and diamonds, respectively. Many mineralised urbanisations do not survive the discontinuation of mining activities (Fafchamps et al., 2017), which results in post-mining landscapes characterised by degraded landscapes (Kivinen, 2017: 1). This often leads to the immediate or gradual abandonment of some accompanying urbanisations within these regions (Fafchamps et al., 2017), such as that observed in the urban sprawl in America and moving further away from mining and industrialisation (Berger, 2006).

However, some of these urbanisations have persisted, forming big urban agglomerations (Berger, 2006; Bryceson and MacKinnon, 2012; Fafchamps et al., 2017). Johannesburg in the Gauteng province, which has seen consistent urban growth over the years, is a case in point. These mineralised urbanisations are characterised by the co-existence of conflicting post-mining characteristics, secondary and tertiary economic activities and the landscapes culminating from the associated urbanisation processes. Bryceson and MacKinnon (2012) argue that despite the role of mining in developing these urbanisations, most discussions on mining activities are on their implications for restructuring the economies of African cities. The discussions rarely consider the underlying relations between urbanisation and mining activities, let alone their co-existence. More specifically, the role played by mining in shaping urbanisation at different scales is unknown, which is particularly important for understanding and managing mining landscapes and their associated impacts at different scales.

1.2. RESEARCH MOTIVATION

Since the 1980s, there has been a global shift towards investigating the sustainability of mining activities and the emerging question of incorporating post-mining landscapes into future urban development (Berger, 2006; Lorandelle and Haase, 2012; Lei et al., 2016). Bryceson and MacKinnon (2012) suggest that adequate responses to the sustainability challenges presented by post-mining landscapes lie in a deeper understanding of the complex relationship between mining and urbanisation processes. According to Harrison and Zack (2012), this is essential to adequately respond to various urban and societal pressures in Gauteng and other similar contexts of mineralised urbanisation.

In the context of Gauteng, this could also be aided by a better understanding of how mining and urban processes interact spatially. Although several data on mining and urban land uses exist, mainly in the form of land cover or land use data, point and areal data, these data have their limitations in terms of their representation of the earth's surface, which is often oversimplified (Sui, 1994; Pickles, 1999; Kwan, 2002 and Mackenzie et al., 2017). Additionally, several studies in this context have argued that a lack of data, particularly baseline data, on mining-related activities has significant implications on the management and, subsequently, the understanding of mining landscapes in Gauteng. GDARD (2009, 2012) and Bobbins and Trangos (2018) argue that a better understanding of the Gauteng mining landscape requires the availability, accessibility and integration of various mining-related data for further analysis. Similarly, Heath (2009) and the Centre for Environmental Research (CER) (2012) note the inaccessibility of mining-related data as a concern. According to Watson and Olalde (2019), this accompanies the lack of communication among various data custodians of mining-related data, which leads to duplication of efforts, non-comparable data, and data veracity issues. This results in the siloed analysis of data and decision-making, which does not consider all available data and characteristics of the Gauteng landscape in their entirety and adds to the challenge of managing and understanding mining landscapes. These studies, therefore, point towards the need for an information system that enables the integration of various data on mining-related issues to facilitate communication and knowledge sharing amongst stakeholders, data interoperability, more detailed analysis, and better understanding and management of the mining and post-mining and urban landscapes.

Some studies, such as Harvey (2018), have argued that the fourth industrial revolution presents a unique opportunity for adopting new technologies, such as Geographic Information Sciences (GIS),) including Artificial Intelligence (AI) and machine learning, which are vital for managing mining and urban activities and landscapes. GIS has been widely used in spatial planning, combining geospatial information in different ways – using symbolisation or layers and enabling the visual extraction and communication of new information. GIS has a powerful capacity and great potential to support land use planning. GIS allows for capturing, storing, managing, manipulating, visualising and analysing information on the earth's surface (Burrough and McDonnell, 1998; Goodchild, 2007). While initially based on empirical foundations, GIS has since evolved to incorporate geographically referenced information into conceptual frameworks used in the social sciences (Goodchild and Janelle, 2010). This provides a framework for integrating multiple layers and variables, which is essential for gaining new insights into spatial relations and historical and morphological conditions of places (Page and Ross, 2015). Thus, GIS-based tools and frameworks are especially useful in regions with a rich and complex spatial history, where such spatial characteristics and patterns can be unified (Hillier, 2010; Alp and Guchan, 2017).

Several studies, such as He et al. (2015) and Sang and Piovan (2019), have used GIS frameworks for documenting and analysing urban landscapes. Most of these frameworks help investigate individual landscapes and integrate data on a particular aspect of the landscape, such as the environment, culture or heritage. According to Siebert (2000) and Page and Ross (2015), a greater understanding of the underlying historical contexts of urban environments is achievable through harnessing the power of GIS to document, visualise and analyse the spatial history of urban regions. Siebert (2000) also notes that integrating various sets of historical and contemporary data in GIS gives insight into underlying relationships of social, demographic, economic, political, cultural, physical and other phenomena defining a landscape. Some other studies have investigated the applications of GIS frameworks in culture conservation and heritage management. He et al. (2015) use a GIS framework to record and analyse physical and cultural heritage across different scales. At the same time, other studies have investigated the applications of GIS frameworks in improving planning efforts and harmonising relations between various spatial features. Page and Ross (2015) argue that GIS frameworks are not only crucial for understanding the past but are also an invaluable tool in contemporary planning efforts, in particular for improving accessibility as well as the quality of urban space. For example, Wang et al. (2015) use a GIS-based framework to assess land use suitability and support sustainable planning in urban renewal. Such frameworks would be applicable in the context of Gauteng, where there is a need for an integrated understanding of the landscape as a whole, considering both the urban and post-mining characteristics of the landscape. Therefore, the proposed study seeks to respond to the above-mentioned gap by developing a GIS-based framework for the integrated visualisation, conceptualisation and analysis of all characteristics, data and intersections of Gauteng's urban and post-mining landscapes.

This study uses academic literature, historical and contemporary data, documentation, legislation, and survey data to interrogate Gauteng as exhibiting post-mining and urban landscape characteristics.

This research study is based on the tenet that some of the challenges faced by the 'urban landscape' of Gauteng result from a lack of understanding of Gauteng as more than an urban landscape but as a post-mining landscape or a combination of urbanisation and post-mining. This is attributed to the limited evaluation of the intersection between urban and post-mining landscapes in Gauteng. Even more so in Gauteng, where post-mining, mining, and urbanisation co-exist, further blurring underlying relationships.

Post-mining, mining and urban landscapes are complex, and more so when they co-exist. This co-existence presents new challenges, and new dynamics manifest. In addition, data inaccessibility and non-comparable data provide a limited regulatory framework to inform decision-making on managing mining-related activities in urban Gauteng, which has implications for informing the management of the post-mining landscape, mining activities and future development in the province. This research study uses assemblage theory as a philosophical lens and the concepts of post-mining and urban landscapes and GIS as analytical frameworks for integrating data on co-existing landscapes. This is to develop a framework for exploring the past and present characteristics and intersections of urban and mining landscapes and provide a more encompassing representation of the Gauteng landscape. The framework is expected to contribute to knowledge by providing insight into a better understanding of post-mining and urban landscapes in Gauteng by proposing practical tools for decision-making and policy development, with potential societal implications that challenge the conventional representations of these landscapes. Additionally, it has policy relevance by offering insights into the complex spatial relationships between mining and urbanisation in Gauteng and potentially influencing their management in similar contexts.

1.3. RESEARCH SCOPE

Landscape characterisation and conceptualisation, integration of landscape characteristics, and GIS-based tools are the main elements in this research. This research notes that these concepts cover a wide range of topics, which is beyond the scope of this research.

The main contribution of the research is the proposal of a framework for integrating characteristics of the province's post-mining and urban landscapes to understand Gauteng as a combined post-mining and urban landscape. The research conducted contributes to further knowledge of post-mining landscapes in three ways. First, it builds on the existing discourse on post-mining landscapes by investigating the contextual differences in the characterisation of and their impact on the conceptualisation and visual representation of post-mining landscapes. Second, it critically engages with historical and contemporary documentation (geographical, spatial, technological, etc.) of mining-related activities and urbanisation in Gauteng. It also assesses their influence on these landscapes' current understanding and management. Third, this research proposes a framework for the integrated conceptualisation and visualisation (spatial representation) of post-mining and urban landscape characteristics, allowing the exploration of their linkages and relationships. By integrating text, spatial data, survey data, maps, and other forms of data that are seldom analysed together in the same framework, the research contributes materially and theoretically to a better understanding of the post-mining and urban characteristics of the Gauteng landscape. A better understanding of the underlying relationship and co-existence of Gauteng's post-mining and urban landscapes is pertinent to respond to the unique sustainability and societal challenges and dynamics presented by the co-existence of these two landscapes. Moreover, the integrated understanding of Gauteng's post-mining and urban landscapes is important for understanding the province's future developmental trajectories.

1.4. RESEARCH QUESTION, AIM AND OBJECTIVES

The overarching aim of this study was to propose and develop a GIS-based framework for conceptualising, integrating, analysing, visualising and managing the historical and contemporary characteristics of Gauteng's urban and post-mining landscapes.

The specific objectives of this study are:

- To identify and critically analyse local expert knowledge and literature (including historical and current documentation, legislation and mapping of mining-related activities) to ascertain their role in the conceptualisation of Gauteng as an urban and post-mining landscape;
- To propose and design a GIS-based framework for integrating historical and contemporary data to conceptualise the Gauteng landscape as a multi-faceted urban and post-mining landscape;
- To test the usefulness of the proposed framework in informing the representation and conceptualisation of mining and post-mining landscapes in urban development using different mapping techniques. From this to see whether it meets the study's primary objective, i.e. 'to develop a tool in the form of a framework for integrating the complex urban and post-mining characteristics of the Gauteng landscape'.

Based on the research scope and motivation described above, this research aimed to address the following research question:

What are the potential applications and limitations of the proposed GIS-based framework using literature and expert-derived landscape characteristics in conceptualising, integrating, analysing and informing the communication and management of the historical and contemporary characteristics of Gauteng's urban and post-mining landscape?

1.5. THE RESEARCH PROCESS

The research process followed to investigate the research question and achieve the specified research objectives is outlined below. There are three phases in the research process: Research definition (Chapter 1), Literature review (Chapters 2, 3 and 4), and framework development and validation (Chapters 5 and 6).

Phase one of this research process entailed the proposition of the research question and specific objectives. The research question and objectives were proposed based on a comprehensive literature review and document analysis.

Phase two entailed the consultation of literature and identifying the relevant theory to serve as a philosophical lens and suitable mapping techniques through which the research mentioned above question and objectives were approached.

Phase three entailed the processes undertaken in developing the framework, including identification of landscape characteristics, data collection and development of databases, data pre-processing, conceptual framework development, mapping and validation of the proposed framework. In identifying landscape characteristics, tentative characteristics often considered in describing post-mining and urban landscapes and their data sources were identified based on an in-depth literature review and document analysis. The framework was practically developed using a case study of Gauteng, a developed urban area characterised by active mining and post-mining landscape characteristics. In the case study, several surveys were conducted to determine the contextual characteristics of post-mining and urban landscapes in Gauteng. Meanwhile, required data were collected, processed and analysed to establish a supporting database for mapping and validating the characteristics of these two landscapes. The steps taken to develop the framework and mapped results and accuracy details are outlined in Chapters 5 and 6.

1.6. STRUCTURE OF THE THESIS

This thesis consists of eight chapters.

Chapter 1 introduces the research background, motivation and scope, proposes a research question and objectives to be investigated, and outlines the research process. The chapter ends with outlining the thesis structure and providing the key terms used in the study.

Chapter 2 provides a comprehensive background of the study area, Gauteng, covering several topics: regional setting and location of the case study area, mining activities, mining and development, mining regulation and legislation, negative impacts and reclamation efforts. The review involves a mass of literature on the unique situation of the case study, characterised by both urban post-mining and urban landscape.

Chapter 3 introduces the theoretical and philosophical lens used in this research. This chapter also introduces the two landscapes under investigation within this study. The chapter presents assemblage theory, considering key qualities of assemblages and their dimensions. This is followed by an outline of the genealogy of the landscape, ultimately introducing it as a unit of study. The chapter then discusses urban and post-mining landscapes, both globally and locally. The assemblage theory is discussed using the landscape analogy, drawing on the qualities and dimensions of assemblages as discussed in earlier sections of the chapter.

Chapters 4 and 5 detail the methodological strategy and process of the research and justify the methods adopted. Chapter 4 first introduces GIS and its applications in framework development. Chapter 5 outlines the specific methods employed within the research and the steps undertaken. The research methods include document analysis, survey data collection and analysis, case study and experimental study. These methods were used to answer the research question and achieve the objectives.

Chapter 6 illustrates the development process of the framework using Gauteng province as the case study. This chapter starts by analysing the documentary and survey data to identify key characteristics of urban and post-mining landscapes and the required data. It develops and visually illustrates a framework demonstrating the relations between the two landscapes and how they co-exist. The chapter then demonstrates how three mapping techniques can integrate the identified characteristics. The mapping results are presented, along with the results from validation exercises (for discussion in Chapter 7).

Chapter 7 discusses the results presented in the previous chapter and their relations to the broader theoretical and thematic literature consulted.

Chapter 8 concludes the thesis, summarising the main research findings. This chapter also highlights the research contributions while also explaining the research limitations. Finally, recommendations for further research are presented.

1.7. KEY TERMS USED IN THIS STUDY

Landscape: This study considers the landscape as a unit of study for investigating the complex relationship between mining and urbanisation in Gauteng, South Africa.

Urban landscape characteristics: Refers to characteristics most associated with urbanisation. These characteristics are identified from the literature and local experts.

Post-mining landscape characteristics: Refers to characteristics associated with post-mining and mining activities and processes. These characteristics are identified from the literature and local experts.

Local experts: This refers to the surveyed participants in this study. The research participants are experts or have extensive experience within the research area or topic.

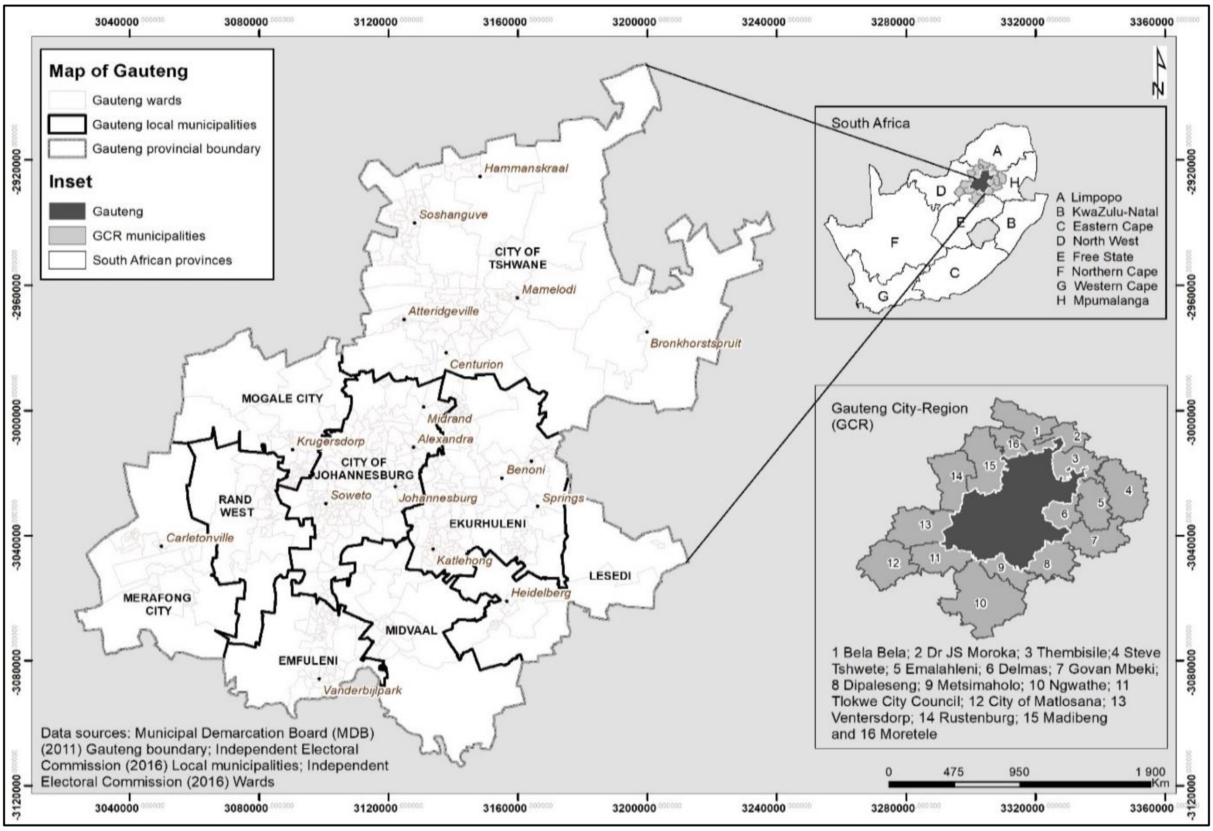
CHAPTER TWO: OVERVIEW OF STUDY AREA: GAUTENG AND ITS URBAN AND POST-MINING LANDSCAPE

2.1. INTRODUCTION

Gauteng has similar characteristics to many other urban spaces emerging after the discovery of minerals, where there is limited understanding of the ongoing relationship between the two landscapes. Therefore, familiarity with this region's mining activities forms a necessary background for understanding the relationship between mining, post-mining and urban landscapes and how the characterisation of these processes can be integrated for a holistic understanding of the landscape in question. This chapter is divided into four parts. It starts with a general overview of the study, followed by an introduction to urbanisation and mining activities in Gauteng and broader South Africa and a discussion of how mining has influenced development in the region.

2.2. REGIONAL SETTING

Gauteng is the smallest of the nine provinces in South Africa (Bredenkamp et al., 2006), covering a landmass of 18 176 square kilometres (km²). The provinces of Limpopo, Mpumalanga, Free State and North West surround Gauteng, as shown in Map 1.



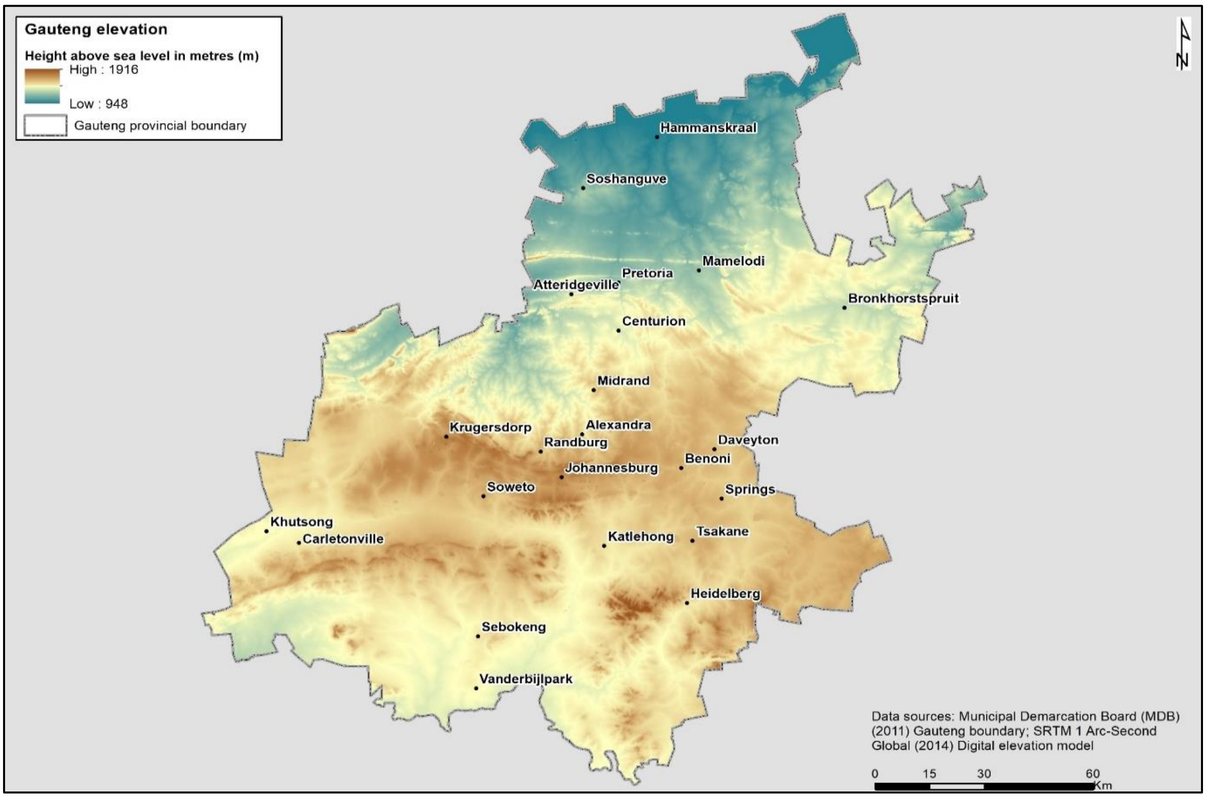
Map 1: Map of the study area, Gauteng Province. Source: Author (2023).

The province comprises nine local municipalities, including three metropolitan municipalities (the City of Johannesburg, the City of Ekurhuleni and the City of Tshwane) and two district municipalities. The two district municipalities are Sedibeng District Municipality (including Emfuleni, Lesedi, and Midvaal) and West Rand District Municipality (including Mogale City, Rand West City, and Westonaria) (Mkhize and Khanyile, 2020).

The province is at the core of the Gauteng City-Region (GCR) (bottom inset in Map 1), which is made up of an interconnected collection of municipalities, conurbations and city hubs that collectively make up the economic nucleus of the country (Gauteng City-Region Observatory (GCRO), 2015). It incorporates smaller centres in Gauteng and its surrounding municipalities. The GCR is geographically poly-centric in shape and is anchored by the three metropolitan municipalities (Wray, 2010).

2.2.1. Topography

The Gauteng province is located over the interior plateau of South Africa, with a height of 1500 metres (m) above mean sea level (Grobler, 2006; Dyson, 2009). However, altitudes vary from 1081m to 1899m above sea level. For example, Johannesburg is characterised by gently rolling topography, with gentle hills to the west, east and south. The Witwatersrand, on the other hand, which straddles the centre of the province, lies at 1700 and 1800m above mean sea level, and the elevation decreases towards the northernmost parts of the province (Dyson, 2009).



Map 2: Elevation map of Gauteng. Source: Author (2023).

2.2.2. Geology

The Gauteng province is famous for the scores of ridges forming the outcrops of the Witwatersrand, which came into existence 2970 million years ago, with its accumulated sediments of the Witwatersrand supergroup (Sutton, 2012). The geology of the study area mostly consists of quartzite, conglomerates, and shale of the Witwatersrand supergroup (Figure 1). The Witwatersrand supergroup comprises the Central Rand Group and the West Rand Group. The soil in the province has a clay content of 10 -30% (Grobler, 2006). This supergroup characterises three Gauteng municipalities, namely, the City of Johannesburg, Ekurhuleni, and the West Rand District, along with smaller urban centres (Mubiwa and Annegarn, 2016). Despite this, the physical geography of Gauteng has been reported as somewhat stable – except for the disruptions that result from the impacts of decades of mining, such as acid mine drainage after gold mining, wetland degradation and sinkhole formation (Mabin, 2013), which continue to alter the physical geography of the province.

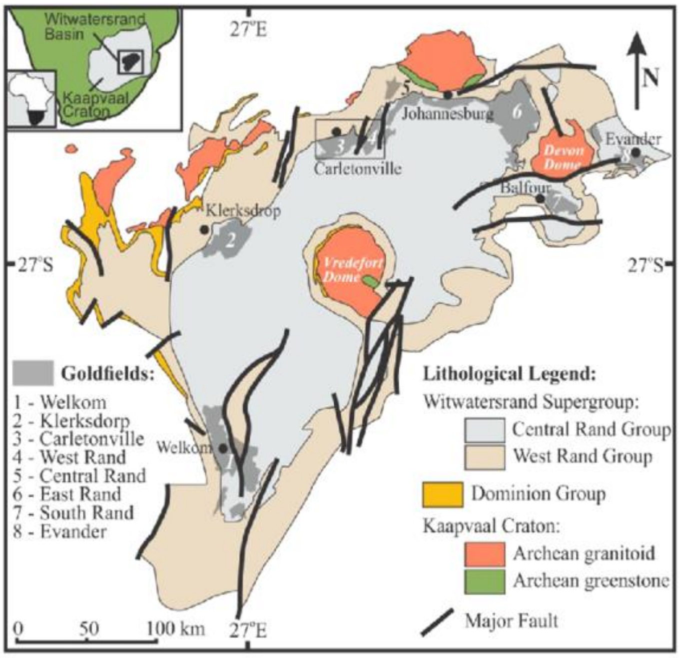


Figure 1: Geology of the Witwatersrand supergroup[1]. Source: Zhang et al. (2023).

2.2.3. Climate

Gauteng falls in the country's summer rainfall climatic zone region, the Moist Highveld Grassland (Dyson, 2009). This climatic region is characterised by warm to hot temperatures. On the one hand, the maximum temperatures (Figure 2a) average 22.4°C in the south and 25.5°C in the north (Taljaard, 1996;

[1] The cover sequencing of the Ventersdorp and Transvaal supergroups were removed in this illustration of the geology of the Witwatersrand supergroup (Zhang et al.., 2023).

South African Weather Services (SAWS), 2023). On the other hand, the lowest temperatures average 10.9°C in the south and 11.9°C in the north (Figure 2b) (SAWS, 2023).

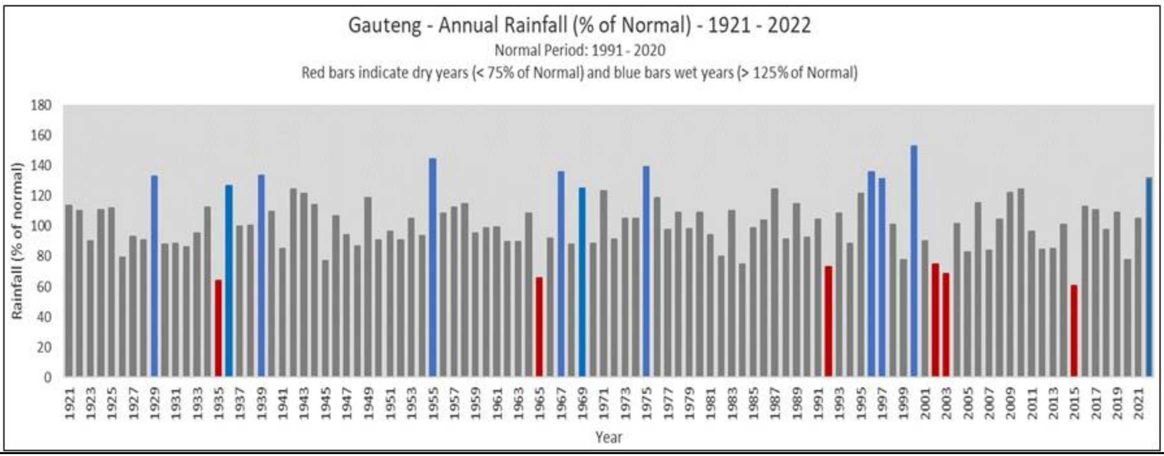
Under this climatic region, most parts of the province receive summer rainfall as weather systems are conducive to convective development (Gijben, 2012). The elevated parts of the province receive 700 millimetres (mm) of rain per annum, while areas of decreased elevation in the north of the Magaliesberg receive 600 mm per annum. According to SAWS (2023), Gauteng has experienced normal rainfall in the past seven years (Figure 2c). In contrast, Johannesburg has had an average of 69 rain days and Pretoria 65 between 1991 and 2020.

a)

Maximum Temperature (°C) overview for some long-term climate stations for 2022									
Station	Average -2022	Normal (1991-2020)	Rank (Highest since 1951)	Highest Annual Average (since 1951)	Lowest Annual Average (since 1951)	Highest Daily - 2022 (Date)	Highest Daily (since 1951)	Lowest Daily - 2022 (Date)	Lowest Daily (since 1951)
Gauteng									
OR Tambo (Jhb)	22.4	22.5	25	24.2 (2015)	21.5 (2001)	32.4 (2022-10-04)	36.2	11.7 (2022-06-15)	2.5
UP Exp Farm (Pta)	25.5	25.1	17	27.6 (2015)	24.3 (1955)	34.3 (2022-10-06)	40.1	14.2 (2022-05-12)	6.8

b)

Minimum Temperature (°C) overview for some long-term climate stations for 2022									
Station	Average -2022	Normal (1991-2020)	Rank (Highest since 1951)	Highest Annual Average (since 1951)	Lowest Annual Average (since 1951)	Highest Daily - 2022 (Date)	Highest Daily (since 1951)	Lowest Daily - 2022 (Date)	Lowest Daily (since 1951)
Gauteng									
OR Tambo (Jhb)	10.9	10.2	15	11.6 (2019)	8.0 (1951)	19.0 (2022-02-03)	23	-2.3 (2022-06-16)	-9.7
UP Exp Farm (Pta)	11.9	11.7	7	12.4 (2019)	8.0 (1951)	18.9 (2022-10-13)	25.7	-1.6 (2022-06-16)	-6.4



c)

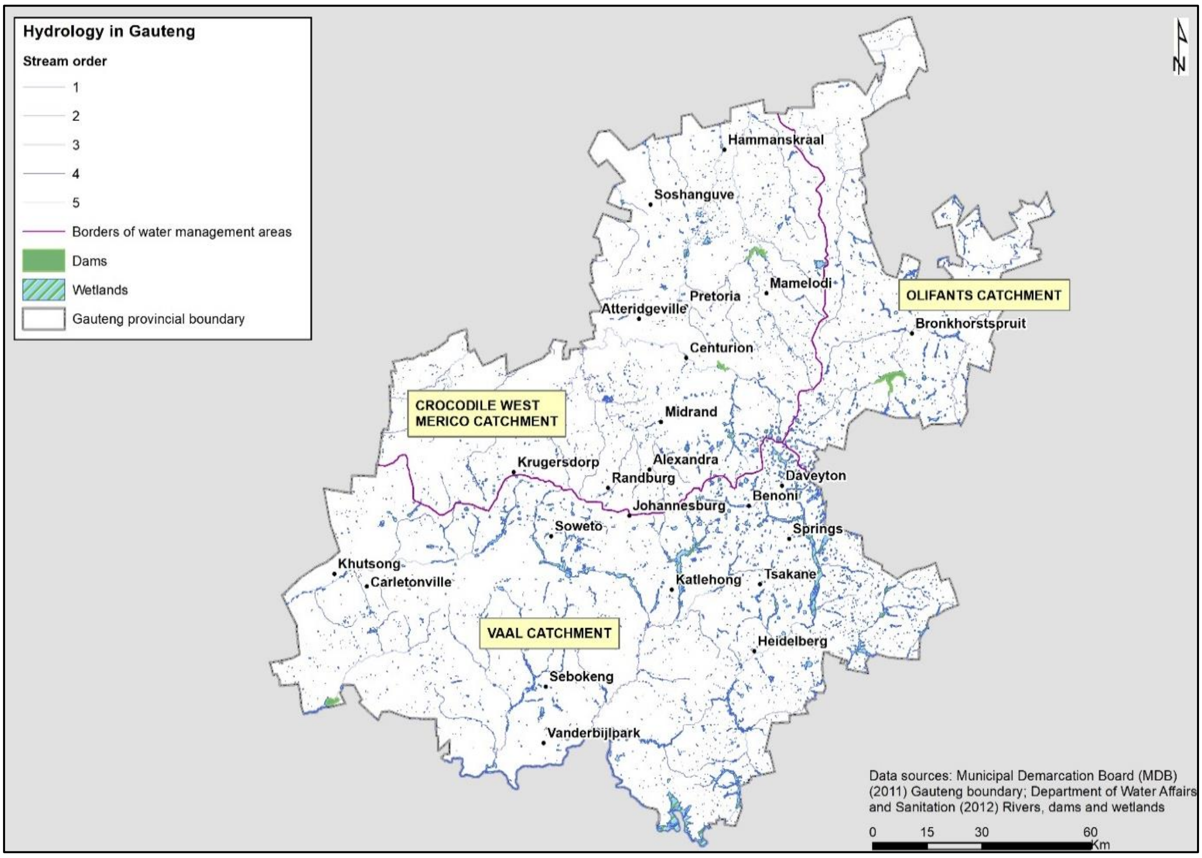
Figure 2: Simplified Gauteng climate data (adapted from the South African Weather Services (SAWS), 2023). a) Maximum temperatures in Gauteng. b) Minimum temperatures in Gauteng. c) Gauteng annual rainfall statistics - based on average rainfall.

However, despite the variations in the region's topography, rainfall and temperatures, the province experiences similar climatic characteristics for the most part. Although recent years have recorded gradual temperature and rainfall pattern changes (Engelbrecht et al., 2015), these changes, combined with rapid urbanisation, population growth and poorly planned settlements, pose significant disaster risks for the province.

2.2.4. Hydrology

Gauteng lies within a major watershed divide. It sits on an escarpment, forming a draining ridge of three major rivers: the Crocodile, Olifants, and Vaal; and their related water management areas: the Olifants catchment, the Crocodile West Merico Catchments and the Vaal Catchment) (shown in Map 3). Consequently, water flows out of Gauteng (Parker et al., 2017). As a result, Gauteng is one of the largest urban areas in the world without a major water source nearby, thereby receiving water from Lesotho to sustain the demand and supply in the region (McKenzie and Wegelin, 2009; Parker et al., 2017).

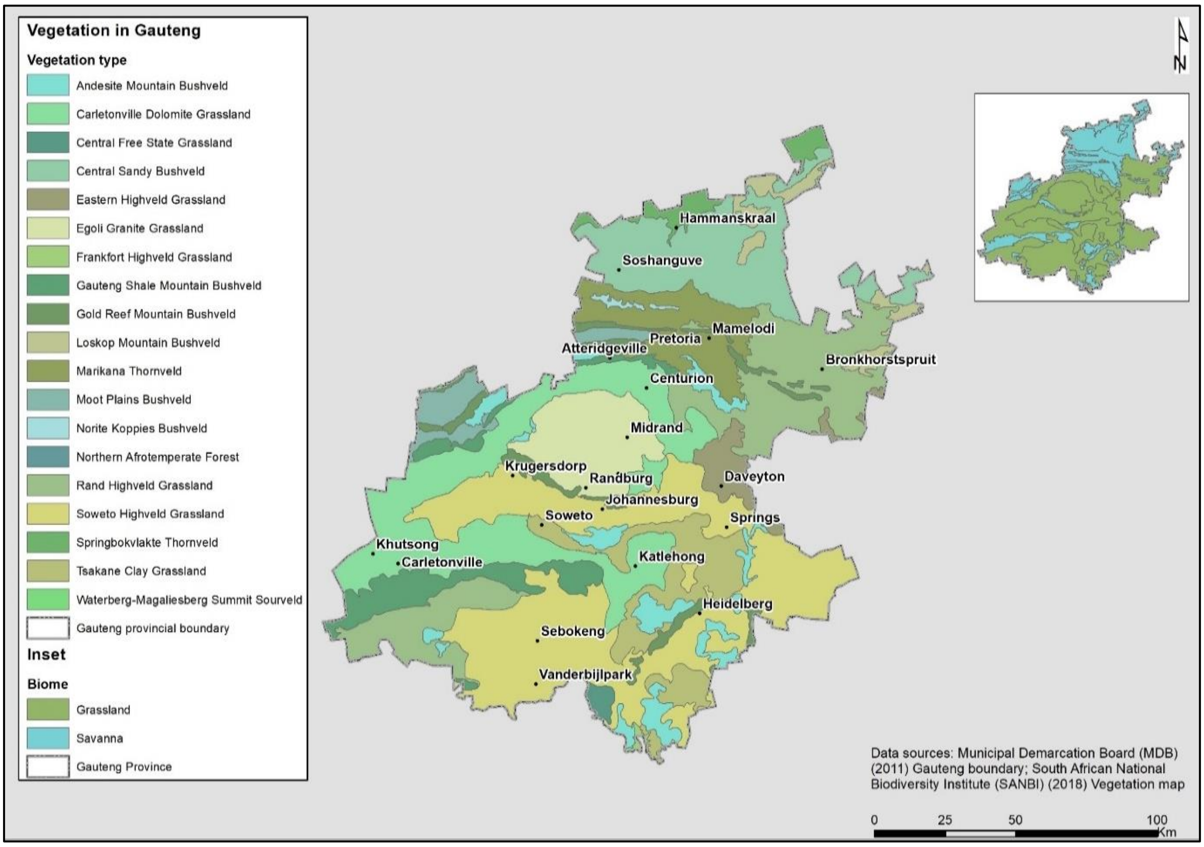
Presently, most of the water in the region is supplied by Rand Water, which gets its water from the Vaal Dam – transporting it over a network of over 3500 km of pipes to 58 reservoirs across the province, while smaller quantities of the region's water supply are from Magalies Water (Muller et al., 2018). Nevertheless, recent decades have seen increased demand for water to meet economic and urban needs, suggesting that water security is a critical strategic consideration in the region (McKenzie and Wegelin, 2009; Muller et al., 2018). Moreover, minimal local water sources mean that Gauteng can never take its water security for granted (Parker et al., 2017).



Map 3: Hydrology and water supply in Gauteng. Source: Author (2023).

2.2.5. Vegetation

Apart from the hydrological and physiological considerations of the province, the soils to the far south and far north of the city tend to be sandy, owing to the province's history as a grassland biome in the south and savanna in the north (Map 4) (Kgatla et al., 2022). The province's grassland and savanna biomes support various grassland species, small trees, bushes and bulbous plants (Bredenkamp et al., 2006).



Map 4: Vegetation distribution in Gauteng. Source: Author (2023).

Additionally, Gauteng was predominantly a farming and pastoral area before the discovery of gold. The discovery of gold has, over time, resulted in a sharp decline in agricultural land - now primarily located at the periphery of the province - and converted from a pastoral economy into an industrial one. The remaining agricultural land availability is plagued by many concerns, such as encroachment by other land uses, unsustainable farming practices, safety and security, and concerns around their water requirements (Storie, 2014; Maree and Khanyile, 2017).

2.3. SOCIO-ECONOMIC CONDITIONS

2.3.1. Social conditions

As the economic hub of South Africa, Gauteng is the most populous province in the country, boasting a population of 15.1 million people (StatsSA, 2023a). However, while the long history of human habitation in the region is often traced back to the formation and inhabitation of Johannesburg, Pretoria, and the surrounding areas, archaeological evidence of hominin habitation stretches back millions of years in the ridges and valleys characteristic of the province, predating European settlement in the region (Mabin, 2013).

The province has experienced significant population growth over the past few years, with an estimated 2.6 million more residents in the last five years (Gauteng Provincial Government (GPG), 2023). The national population growth rate in South Africa has been estimated at 1.5%, while that of Gauteng consistently exceeds this at 2.5% (GPG, 2023; StatsSA, 2023a).

This high growth rate, leading to a substantial increase in the population, is attributed to natural growth processes and an influx of migrant workers coming to the region from outside the province in search of employment opportunities (StatsSA, 2022). According to the GCRO's Quality of Life (QoL) Survey IV (2015/16), as many as 18% of those who come to the province in search of job opportunities eventually reside in informal settlements (Culwick and Dawson, 2016). Informal settlements comprise uncoordinated and fragmented housing developments (Kilian et al., 2005). These informal settlements are primarily located on the urban fringe, where economic opportunities are accessible in proximity (Hamann et al., 2018). However, residents also face challenges accessing the job market (Culwick and Dawson, 2016). Hamann (2003a, 2003b) states that most informal settlements lack basic services such as water, sanitation, and electricity, rendering their residents vulnerable.

Despite the province being the economic hub of South Africa, it is characterised by high levels of poverty. According to de Kadt et al. (2021), 36% of Gauteng households live below the poverty line. Additionally, unemployment in the province has increased to 34.4% (StatsSA, 2023b).

2.3.2. Economic conditions

Gauteng province gained prominence through the discovery of gold along the Witwatersrand basin in 1886, with the initial mining activities concentrated in the City of Ekurhuleni, the City of Johannesburg, and the West Rand District Municipality (Harrison and Zack, 2012). Subsequently, this region underwent rapid development and urbanisation after the gold boom, establishing itself as the economic hub and the fastest-growing province in South Africa (Harrison, 2007; StatsSA, 2011).

Nonetheless, the mining industry experienced a decline in the 1970s, which led to increased exploration of various minerals and commodities across the province, moving further away from the initial mining areas (Harrison and Zack, 2012). This expansion introduced smaller mining towns and communities, moving away from the mining belt and, over time, coming together to form an agglomeration of urban space (Bryceson and MacKinnon, 2012) at the core of the province, radiating outwards on either side of the Witwatersrand belt. Despite this decline in mining activity, Gauteng remains the economic stronghold of South Africa, owing to the diversification of its economy into more secondary and tertiary activities (Bryceson and MacKinnon, 2012).

The province is the most significant contributor (33.1%) to the South African economy, with the highest growth rate reported in 2022 (StatsSA, 2023ab). With the continued decline of mining in the province, the most significant contributing sectors are finance (31%), manufacturing (17%), trade (13%), personal services (11%), government (10%), transport (8%), and other (9%). As such, the province attracts a significant portion of the working-age population (15-64 years) in search of employment (StatsSA, 2022).

2.3.3. Land use

Several maps depict land use or land cover[2] in Gauteng. This study uses the latest available land cover and data from the Department of Environmental Affairs website[3]. GeoTerra Image (GTI) created the data, classified from 2020 imagery.

The above-mentioned land cover or land use data comprises 72 land cover classes and can be broadly classified into nine broad categories, which are Forested[4], Shrubland[5], Grassland[6], Waterbodies[7], Wetlands[8], Barren lands[9], Cultivated[10] and Built-up and Mines and quarries. The areal coverage of each

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[2] Land cover is that which can be observed from satellite imagery, while land use refers to the actual use of the land regardless of the formal categorisation (Hamann and Ballard, 2022), which also implies the transformation of the natural environment.
[3] https://egis.environment.gov.za/
[4] Class comprises contiguous forest (low contiguous, dense, thicket, woodland, plantation sparse, open and temporary unplanted).
[5] Class comprises shrubland (low).
[6] Class comprises grassland (natural and sparsely wooded).
[7] Class comprises natural pans (flooded at observation times), artificial dams (including canals) and artificial sewage ponds.
[8] Class comprises herbaceous wetlands (currently and previously mapped).
[9] Class comprises natural rock surfaces, dry pans, eroded lands, bare riverbed material and other bare.
[10] Class comprises cultivated commercial permanent orchards, commercial annual crops pivot irrigated, commercial annual crops non-pivot irrigated, commercial annual crops rain-fed / dryland, subsistence / small-scale annual crops, fallow land & old fields (trees), fallow land & old fields (bush), fallow land

of these land cover or land use categories is presented in Table 1. Table 1 shows that the land cover or land use characterising most of the land in Gauteng is grassland (32%). Hamman and Ballard (2022) argue that 86.2% of Gauteng's land cover or land use falls under the non-urban category. Thus, a large amount of land categorised as grassland indicates that some parts of Gauteng have not been converted to urban land uses (Hamann and Ballard, 2022). Grassland as the dominant land cover or use in Gauteng is followed by cultivated land (27%), built-up land (22%), and forested land (13%), with the remainder of land cover or use classes (shrubland, wetlands, waterbodies, mines and quarries and barren land) occupying less than 3% of land each.

Table 1: Areal extent of land cover or land use classes as at 2020. Source: Author (2023).

LAND COVER/ LAND USE	**THE AREAL EXTENT IN KM^2**	**PERCENTAGE (%) OF THE PROVINCE COVERED BY LAND COVER/USE CLASS**
Forested land	2397.78	13.20
Shrubland	9.73	0.05
Grassland	5872.02	32.32
Waterbodies	134.53	0.74
Wetlands	458.05	2.52
Barren land	148.18	0.82
Cultivated	4852.20	26.70
Built-up/urban	4086.91	22.49
Mines and quarries	211.08	1.16
Total area (km^2) of province	18170.49	100%

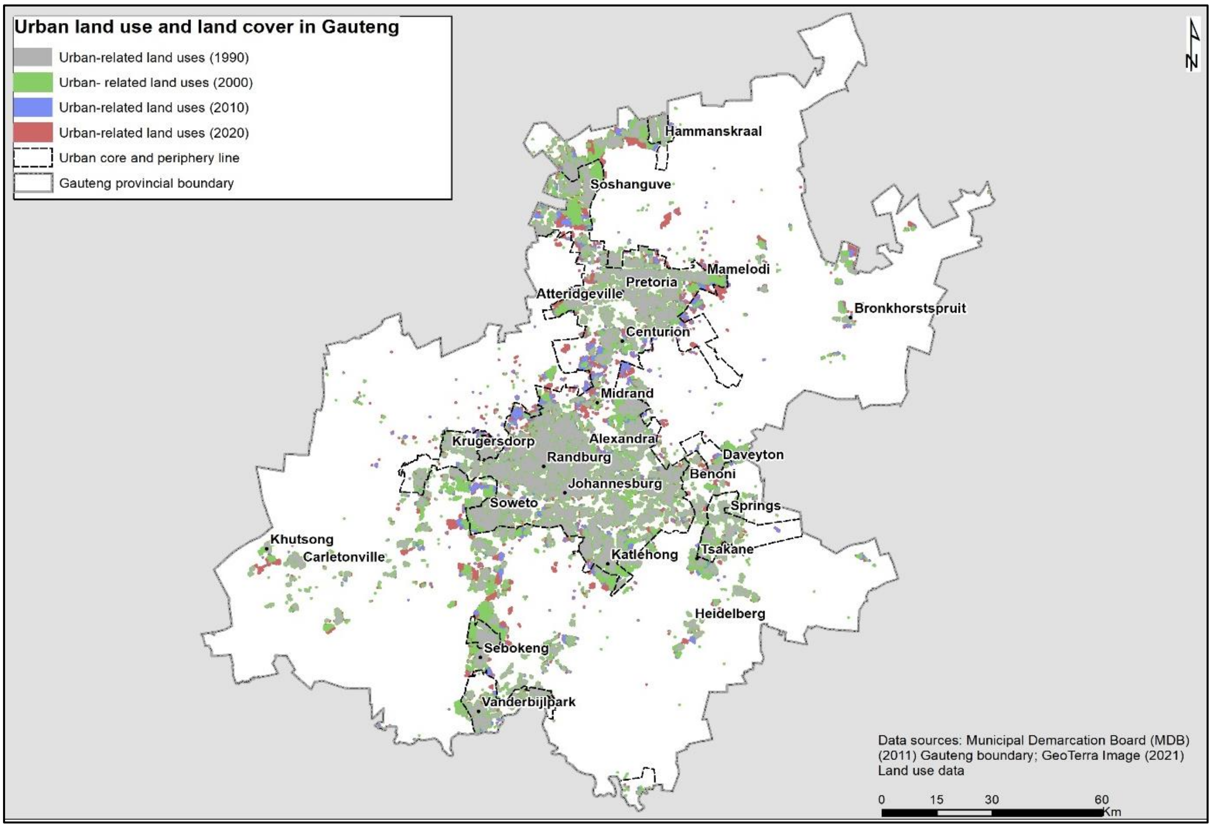
This research is interested in the land cover or land uses related to Gauteng's post-mining and urban nature. According to this data, only 22% of Gauteng province is characterised by built-up or urban land cover or land use. By contrast, only 1% of the Gauteng landscape is characterised by mines and quarries. An advantage of using this data is that it is serial data, which enables a time series or land cover or land use change analysis of the data, and using the older layers provides some insight into historical mining and urban land cover/use. However, it should be noted that there are some limitations to using this data. For example, while mines and quarries comprise 1% of the Gauteng areas, mining-related buildings are not included in this 1% as they are recorded in the built-up class and classified under urban. This shows the extent to which Gauteng's urban and mining landscapes are intertwined. Additionally, this data only considers the surface characteristics of mining, while most of the mining activities in Gauteng have been underground.

& old fields (grass), fallow land & old fields (bare), fallow land & old fields (low shrub) and fallow land & old fields (wetlands).

Moreover, another limitation of mainly relying on this data as a proxy for mining and urban landscapes is that this data uses low-resolution satellite imagery, where the resolution is not as high as ideal, which affects the classification of land cover/use classes. Moreover, this data only considers the visual and physical manifestations of post-mining and urban landscape characteristics. As such, most of the underground mining that characterised this region initially is not included in classifications.

2.4. URBANISATION IN GAUTENG AND SOUTH AFRICA

According to Mukoko (1996), a complex issue with South African urban landscapes is their dualistic nature, owing to their colonial and segregationist past. In this context, urban development is associated with the apartheid segregationist regime from 1948 to 1994 - where non-white population groups were forced to live in peripheral areas. These peripheral areas had limited access to basic services and were far from economic opportunities and other amenities. This has had a lasting yet unequal impact on Gauteng's urban spatial form. In democratic South Africa, these apartheid planning laws have led to institutional fragmentation and settlements with distorted patterns and spatial inefficiencies (Pillay, 2008; Napier, 2009; Turok, 2012; Cilliers et al., 2014). Map 5 shows the urban land uses, showing the increase in the spatial footprint of urban land in the province. The province's core is indicated in a dotted line on the map.



Map 5: Urban land use and growth in Gauteng. Source: Author (2023).

Since 1994, urban planning has been characterised by ambitions of enhancing equity by providing basic infrastructure and services (Turok and Parnell, 2009; Culwick et al., 2019). These ambitions are primarily driven by the urgent need to redress inequality and injustices of the segregationist past. This has been done by removing restrictions on free settlement and movement, re-engineering the urban form through the spatial development framework (SDF), restricting urban sprawl through infill programs and removing housing segregation based on ethnic identity (Marais and Ntema, 2013; Ruhiiga, 2014; Culwick et al., 2019).

According to Pillay et al. (2006), South Africa's urban development policies, as they appear in the government's white paper (Department of Housing, 1997), highlight four types of urban areas, namely: a formal urban area, rural formal or commercial farming areas, tribal areas, and an informal urban area. These include urban areas that are centres of urban governance in the form of metropolitan governments and economic and social opportunities (Ruhiiga, 2014). Cilliers et al. (2014) describe these urban landscapes as areas characterised by rich biodiversity, cultural diversity and steep socio-economic gradients. Additionally, the rate of expansion and urbanisation within these urban areas has taken place unevenly across the country, with the fastest increases noted in Gauteng (the setting for this study) and Cape Town (Turok and Borel-Saladin, 2014).

Gauteng is the economic hub of South Africa and the African continent, owing to its industrial and economic development (Chakwizira et al., 2018). This province's industrial and economic development has been characterised by employment opportunities and access to essential services, contributing to its rapid urbanisation and migration (Nhamo et al., 2021). However, according to Hamman and Ballard (2022), the extent to which parts of Gauteng are urbanising is a significant policy concern, as the province now faces several challenges, such as population growth and economic pressures driving excessive land transformation. This transformation is evident in the distribution of the population across the province (Bobbins and Culwick, 2016) and numerous land cover changes, such as a decrease in water, smallholdings and agriculture within the province, while also pointing towards an increase in degraded land. On the one hand, the bulk of the land transformations within the province are characterised by settlement expansion at the province's core. These findings mirror those within the South African Environmental Outlook Report (SAEOR) (DEA, 2017), which suggests that the provincial population and household numbers are rising, the latter being attributed to fewer people living in each household.

On the other hand, according to DEA (2017), over 55% of provincial land has been transformed for economic and consumerist activities such as mining, agricultural practices and food production, as noted in Chakwizira et al. (2021). While important catalysts for sustaining the province's economy, these activities are often irreversible, permanently rendering some parts of the province unsuitable for human occupation (DEA, 2017). This, in turn, continues to drive the demand for human settlement land

and indirectly contributes to the loss of biodiversity and continued pressure on available and potentially environmentally sensitive ecosystems such as wetlands and indigenous grasslands. Moreover, rapid urbanisation highlights the spatial inequality in some areas within this region, challenging the potential implementation of sustainable contemporary urban planning and environmental management practices in the province.

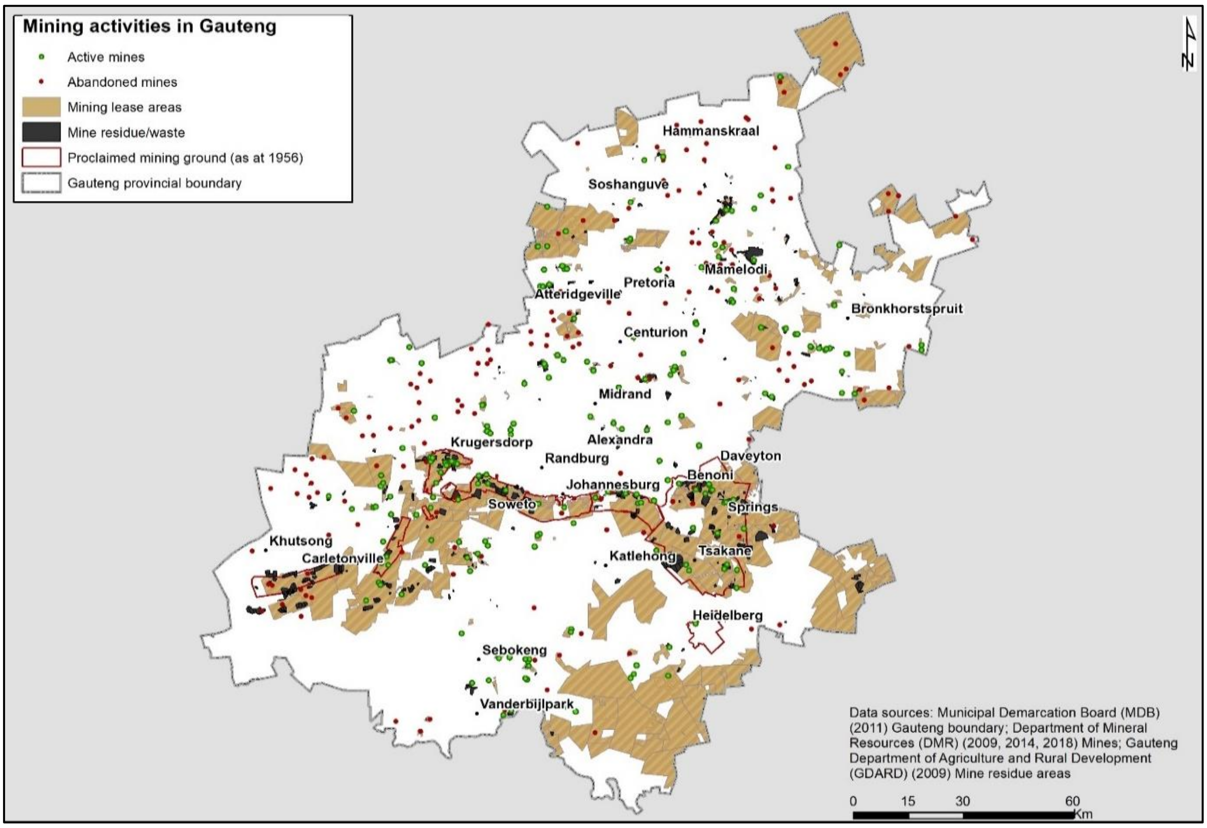
2.5. THE MINING ACTIVITIES OF GAUTENG

The Witwatersrand basin is the oldest large-scale mining area in South Africa, owing to the discovery of gold in Langlaagte in 1886 (Crush, 1986; Cammarck, 1990; McCarthy, 2010; Pert et al., 2013). The Witwatersrand gold comes from a 56-kilometre (km) rocky outcrop extending east-westerly across the central GCR (Trangos 2018). It cuts across the province's West, Central, and East Rand regions (Map 6). The initial mining activities of the Witwatersrand were located on proclaimed mining grounds in the City of Ekurhuleni, the City of Johannesburg, and the West Rand District Municipality (Heath 2009), as shown by the dark red outline on Map 6. Gold prospection in the region produces a 100 km physical belt called the Witwatersrand mining belt (Heath, 2009).

The Witwatersrand mining basin has yielded over 52 kilotonnes of gold since its discovery in 1886, a significant increase in gold production compared to 523 tonnes of gold extracted in the region's first year of gold mining (Robb and Robb 1998; Stafford, 2015, 2016). Gold production in the province has played a significant role in making South Africa the leading producer of gold for over a century, with an estimated contribution of between 33 - 40% of world production (Stafford, 2015, 2016). Furthermore, at the local level, Gauteng is the most productive producer of gold and other commodities in South Africa (Cowey, 1994; OECD, 2011) and the fastest urbanising province in South Africa and the rest of the African continent (Harrison, 2007; StatsSA, 2011).

Early mapping of the region in 1956 by Fair et al. (1990) shows that just a few settlements accompanied these mining activities on either side of the mining grounds to make commutes shorter for labour (Harrison and Zack, 2012). However, contrary to the early mining days (in the 1880s), where gold mining along the Witwatersrand was undertaken using picks and shovels to reach the gold-bearing gold ore, new techniques were introduced and adopted in the 1960s to increase gold extraction to meet the global demand and significantly impacted the rate of extraction (Heath, 2009, Robb and Robb, 1998). Currently, however (as also demonstrated in Map 6), mining-related activities are no longer limited to the central parts of the province, and large mining lease areas (concessions) are in the far south (around Heidelberg) and in the northern parts of the province (Trangos and Bobbins, 2018).

These mining concessions (hatched on Map 6) are managed by large mining corporations, leasing the area for a defined period from the mineral rights holder and primarily responsible for mining and reprocessing gold ores. Map 6 presents a picture of the mining activity in Gauteng and shows that the province is characterised by abandoned (this includes ownerless and derelict mines) and active mines. Additionally, the province is characterised by mine waste – discussed in subsequent sections.



Map 6: Mining activity in Gauteng. Source: Author (2023).

Recent studies (Harrison and Zack, 2012; Spay, 2014; Marais, 2018) indicate a decline in the mining industry's contribution to the economy as it now only constitutes a small percentage (2%) of the provincial Gross Domestic Product (GDP) (The Real Economy Bulletin, 2016). However, despite this, the mining sector maintains its importance to the regional economy as the mining of gold, diamond, and coal production still occurs here and is still the most significant contributor to foreign exchange revenue. Thus, mining activities along the Witwatersrand continue to benefit the state through considerable revenue and specific individuals by providing some of the unemployed with ways to earn money. According to Cowey (1994), the revenue generated from employment in the mines and supporting industries alone has been an essential catalyst for sustaining the economy and infrastructural development in South Africa.

2.5.1. From mining to post-mining landscape

Much of the gold mining ceased in the 1970s as mining operations started digging deeper, and the production of gold became unprofitable, leaving more than 270 tailing dams covering over 400 square kilometres (km^2) in the surface area around the Witwatersrand basin (Stafford et al., 2015; Stafford, 2016; Bobbins, 2018). As a result, a large acreage of prime Gauteng land is characterised by mining or remnants of mining activities such as abandoned mine shafts (as shown in Figure 3) or mine waste.

Figure 3: A boy playing close to a discontinued mine shaft in Ekurhuleni. Source: Heath (2009).

Mining activities have various visible impacts on the environment, such as tailings, soil displacement, changes in land used for agricultural purposes, increased loss of biodiversity and degradation of water source quality through Acid Mine Drainage (AMD) - which contaminates both surface and groundwater sources (Martin et al., 2014; Moncur et al., 2014; Stafford et al., 2015; Stafford, 2016). There is also a considerable presence of overburden materials in the form of rocks and soil that were removed to gain access to ore deposits along the Witwatersrand, sometimes stored in dumps (Festin et al., 2019). Additionally, mining also results in waste dumps, which are made of heterogeneous coarse-grained rock usually stored at the mine site, and they are an environmental concern because of AMD (Figure 3). However, some waste rocks can be stored in tailing dams to prevent AMD (Rankin, 2011).[11]

[11] Acid mine drainage is created when mining waste comes into contact with water and oxygen and releases acid, sulphates and metals (Ashton et al., 2001; Sheoran and Sheoran, 2006).

Figure 4: Iron hydroxides precipitating into a river in Ekurhuleni. Source: Sutton (2012).

These post-mining landscapes are a crucial signifier of the lax legislation that has characterised the mining industry in South Africa (Mhlongo and Amponsah-Dacosta, 2016), which is attributable to the part gold and mining played in the expression of South Africa's political economy. This has resulted in the mining sector being plagued by regulatory uncertainty, which undermines the positive role that mining can play in the country's development. The following sections discuss the different aspects of Gauteng's post-mining landscape. Starting with a discussion of the regulation of the mining sector, followed by the negative externalities of mining and ending with the discussion of its rehabilitation and economic prospects.

2.5.2. Regulation and legislation of mining activities and resultant waste in Gauteng

The severe landscape damage from mining activities was recognised early when the Mines and Works Act (27 of 1956) was enacted. As the impact of mining became apparent, more laws were introduced to regulate the activity within the region. However, these were also closely linked to apartheid legislation at the time. For example, the Mining Rights Act (20 of 1967) led to the rehabilitation of mining grounds near settlement areas and the allocation of this land for the settlement of African, Coloured and Indian population groups (Magubane, 1976; Kilian et al., 2005; Mubiwa and Annegarn, 2013).

The lax legislation around mines and mine waste was replaced by the endorsement of the Minerals Act (50 of 1991), which aimed to ensure that the state and mining company responsibilities to communities surrounding mining activities were met (Mhlongo and Amponsah-Dacosta, 2016). Until then, mines could abandon their operations without much consequence once unprofitable. The Minerals Act changed this when it required mining companies to provide an environmental management programme and a rehabilitation plan stipulating post-mining provisions associated with ecological liabilities (Swart, 2003). Consequently, South Africa has close to 8,000 derelict and ownerless mines (SA Auditor General, 2009; Durand, 2012)[12], many of which are under extended maintenance while awaiting closure certification (Watson and Olalde, 2019; Miralas et al., 2014). Some authors argue that this is deliberate to avoid the assumption of rehabilitation responsibilities by the state. Since the early 1990s, the regulations and legislation of mining activities have seen several revisions, with the democratisation of the country and the ascension of the new South African Constitution (Act 108 of 1996)[13] bringing with it more sustainable thinking in all spheres of government and the corporate mining sector (Republic of South Africa 1996. One such regulation that has been introduced since then is the Mineral and Petroleum Development Act (MPRDA) (Act 28 of 2002), which further reinforced closure legislation (Watson and Olalde, 2019) and made natural resources a collective resource of the people and the state. According to the Act, mining companies are expected to meet the requirements for mine management closure.

Unlike in current-day practices, where mines are designed with mitigation plans (Moreno-Jiminez et al., 2001), proper mine closure was not a priority for mine management with the initial establishment of mines. Therefore, current mining legislation deals with ongoing and abandoned mining activities and seeks to create a legal framework that upholds human rights concerning development and the hazards associated with active mining, mining waste, and pollution. Therefore, despite the MPRDA, mine closure legislation is part of environmental, water, and pollution legislation. The implications are that all spheres of government are effectively responsible for administering the legislation and regulations of mining activities and resultant waste (Bobbins, 2015).

The implications of this are that while the Chamber of Mines of South Africa is recognised as the authoritative voice of the mining industry in South Africa, other government departments also regulate mining activities. These include the Department of Mineral Resources (DMR), the Department of Water Affairs, the Department of Environmental Affairs, and the Department of Agriculture, Land Reform and Rural Development. Under the DMR, mining activities are regulated by the MPRDA (Schutte,

[12] However, there are significant discrepancies in the estimations of how many derelict mines exist in South Africa, with some researchers suggesting that it is around 5000 (South African Auditor General, 2009). Noting also that there have not been any recent abandoned mine audits.

[13] The South African Constitution stipulates that everyone has the right to a healthy environment that does not cause them any harm. Moreover the Constitution also states that mining must be conducted in a manner that is sustainable for present and future generations (RSA 1996, CER 2014).

2014), amended in 2014 to give the department control over mining operations (Kings, 2014). The Department of Water Affairs is regulated by the Water Amendment Act (58 of 1997) and National Water Act (36 of 1998) and seeks to maintain water quality integrity[14]. The Department of Environmental Affairs is regulated by the National Environmental Management Act (107 of 1998), which aims to manage environmental impacts and promote environmental protection (Bobbins, 2015). In addition, mining activities are also governed by the Mine Health and Safety Act (29 of 1996), the Atmospheric Pollution Prevention Act (45 of 1965), the Nuclear Energy Act (46 of 1999) and the Fanie Botha Accord instigated in 1970.

Additionally, the mandate for environmental health, emergency services, and disaster management lies locally, as stipulated under the Spatial Planning and Land Use Management Act (16 of 2013), as the level of government directly impacted by mining waste-related issues. However, the local government is often not equipped with the necessary skills, capacity, and knowledge to deal with these issues (Bobbins, 2015), and the appropriate skills in the context of mine closure are often lacking (Miralas et al., 2014; van Druten, 2017; Watson and Olalde, 2019). Consequently, mine waste and environmental waste-related issues are split between different stakeholders, leading to a fragmentation of responsibilities and various interpretations of the legislation.

Another issue, although less often spoken about, is the general lack of information on some mining activities. Several forms of legislation in South Africa regulate data on mining activities. For example, the South African Space Affairs Act (83 of 1993) is a regulatory framework for outer space data and observation. The Spatial Data Infrastructure Act (54 of 2003) makes prescriptions regarding facilitating the sharing of spatial data. Additionally, the MPRDA, which urges information to be made available voluntarily through regional managers, also expects holders of mining rights to provide annual reports detailing accurate information and data regarding the mineral reserves and resources within the mining areas.

Nevertheless, data on mining activities is mostly not readily available. Several regional studies have reported on the inaccessibility of data on mining and the resultant waste. For example, data inaccessibility has been widely reported in many publications, such as GDARD (2009, 2012), Heath (2009), CER (2012) and Watson and Olalde (2019). GDARD (2009, 2012), in their study of mine residue areas (MRAs) and their suitability for reclamation, argue that a lack of data, particularly baseline data, on mining-related activities has significant implications on the management and, subsequently, the understanding of mining landscapes in Gauteng. Additionally, the failure to provide information on the general functioning of mining activities, which in most instances is neither incriminating nor

[14] Mining is a water intensive economic activity. Moreover, mining has an impact on surrounding water quality (Gunson et al. 2012).

controversial, supports existing suspicions of mining companies' failure to consult with appropriate community members and circumvent environmental impact assessments. This issue is of great concern, mainly since these mining activities occur close to areas zoned for human settlement. Data inaccessibility highlights the lack of compliance by mine management or organisations. It violates the Promotion of Access to Information Act (2 of 2000), which gives effect to the constitutional right of access to any information held by a public or private body required to protect any rights.

2.5.3. Negative externalities of mining activities in Gauteng

A complex governance landscape informs the responsibility taken for the hazardous impacts of mines around Gauteng, often deflected onto surrounding communities. These negative impacts raise the issue of the spatial relationship between mining areas and human settlements in the GCR and change over time (Fair et al., 1959; Mabin, 2013; Khanyile, 2016; Bobbins and Trangos, 2018).

2.5.3.1. Environmental challenges driven by mining-related activities

For a long time, the environmental impacts culminating from the mining activities of the Witwatersrand were overlooked as the benefits of economic development were often more immediate to the surrounding communities, and the impacts appeared long after mining had ceased (McCarthy, 2010). Thus, it has taken a long time to develop an environmental agenda within the mining sector in South Africa.

Severe impacts on public health are associated with living near active and discontinued or closed mines. According to Festin et al. (2019: 382), "in the absence of adequate mining closure management, metalliferous mine tailings, and overburden materials pose serious hazards to human health and agricultural productivity through surface or groundwater pollution, off-site contamination via aeolian dispersion and water erosion…". Health concerns associated with exposure to post-mining wastes include vulnerability to diseases such as asthma, bronchitis and pneumonia. For example, in Roodepoort, there is an old and abandoned gold tailings storage facility adjacent to the community of Davidsonville with unmanaged runoff, seepages and contamination of water sources by acid mine drainage (Trangos, in Bobbins and Trangos, 2018). Similarly, the Tudor Shaft informal settlement in Mogale City is located on land contaminated by mining waste dumps. The residents are exposed to radioactive dust that emanates from these dumps (Bobbins, in Bobbins and Trangos, 2018). A similar case can be seen in Figure 5, which shows the distance between residences and mining operations somewhere in Springs, in the East Rand.

Another example is the infamous case of Riverlea (a township built during the apartheid era) and DRD Gold. Minorities were forcibly moved and relocated to Riverlea, an area close to an abandoned mine dump, which started being a problem when DRD Gold started removing the vegetation over the mine dump in pursuit of remaining gold. The dump reportedly produced high dust levels, affecting the surrounding community through noise pollution and increased dust particulates, leading to respiratory problems (Kings, 2013).

Figure 5: Google Earth image of the distance between mining operations, waste, and residential area in Golden Springs in the East Rand. Another residential area, 700 Scheme (Springs), is located to the west. Source: Google Earth Imagery (2014).

Another study by the Benchmarks Foundation (2017), investigating the impacts of mine tailings and abandoned mines on adjacent communities, suggests that the coincidence of gold and uranium within the Witwatersrand has exposed a considerable amount of radioactive rock. These radioactive rocks are expected to culminate in several radiation risks which manifest in several ways, including unfenced mine waste, particularly slimes or tailings accessible to the unknowing public; informal settlers residing on abandoned mine sites; people stripping radioactive materials from abandoned mine sites and uranium processing plants and selling this to scrap metal dealers; people using tailings sand as a building mix for concrete, cement, and plaster to build houses; dust from slimes/tailings dams and people inhaling or ingesting the dust; runoff of mine water from tailings dams, or seepage into groundwater and plants absorb radioactive substances from the soil on which they grow (Benchmarks Foundation, 2017). They are also toxic for present and future use, meaning that most of this land is excluded from urban development planning and has not been considered for the future expansion of the province.

Nevertheless, Bobbins (2018) argues that while there has been a surge of scientific findings to confirm the impact of mining on the environment, this did not immediately flag the need to act, thus perpetuating a culture of non-compliance. Ultimately, the issues surrounding mining waste have become interwoven with those of fundamental human rights and institutionalised poverty, forcing the shift towards more decentralised environmental governance and the broader participation of non-profit organisations (Bobbins, 2018; Crous et al., 2020). Thus, by the early 2000s, at least from a legal perspective, environmental rights discourse was infused with environmental justice, promoting a culture of inclusivity and engagement in environmental decision-making. With this, the government was forced to reconceptualise its approach to environmental management. At the same time, mining companies became legally bound to consider all the potential impacts of their activities and take reasonable measures to ensure ecologically sustainable mining activity, the recent attempts outlined in the latest Draft Mine Closure Strategy (2021). As such, mining operations must have proper mitigation plans that ensure that environmental impact assessments (EIAs) are carried out regularly, the broader mining industry is working towards sustainable growth, and economic development does not severely degrade the surrounding environment. Nonetheless, considerable work is left to entrench this discourse in practice.

2.5.3.2. Socio-economic challenges driven by mining-related activities

Mining activities have played an essential role in the province's economy. However, mining also brings many social problems despite its wealth. Mine closure and post-mining landscapes increase the complexities of these social problems. Because of the extensive mining wealth, imagining a time without mining is challenging. Mining makes many communities dependent on it. They introduce jobs and significant infrastructural development in some communities and provide fast ways of securing an income when odd jobs do not offer a sustainable living for many (Cowey, 2004).

However, this primarily concerns operational mines, as abandoned mines often cease to exist along with their benefits. The consequence of this is major socio-economic problems in communities surrounding mines that have ceased to operate, including unemployment, limited job mobility, a decline in economic activities, alcohol and substance abuse, and depression in their communities (Crous et al., 2020). Similarly, Marais et al. (2022) have demonstrated the positive impact of mining on crime levels using the example of an analysis of the crime statistics released by the South African Police Services, which showed decreased crime levels as mining grew. They argue that crime originates from the inability to rehabilitate land and mining sites, inhibiting economic development. However, Bobbins (2018) states that, on the other hand, the cessation of mining activities and mine closure has resulted in the development of distressed mining settlements characterised by primarily informal sources of income to sustain livelihoods, thus creating micro-economies. For example, this can be seen in the re-exploitation of some mine dumps by small-scale artisanal gold miners (also known as *zama zamas*) and reselling any findings from their diggings, which has benefited these communities (Bobbins, 2018).

2.5.4. Reclamation efforts of mining-impacted areas

As heaps of mine waste characterise the Gauteng landscape, the possibility of reprocessing the mining waste has been at the forefront regarding thinking about what to do with post-mining landscapes in the region. Several studies (Stafford et al., 2015; CSIR, 2020) suggest that post-mining landscapes can deliver positive benefits through regional economic development and infrastructural gains. Most of Gauteng's post-mining landscapes are considered a health and safety hazard, which has heavily influenced current urban planning, legislation, and the management of these landscapes. In the process, this has invariably led to the exclusion of this land from urban development planning and left out of future expansion plans for the province, despite the increasing demand for prime land with access to services and job and educational opportunities. However, in exceptional cases, some rock dumps can contain traces of gold that can be recovered through reworking. This has been the remaining mine heaps by mining corporations or zama zamas, who often re-exploit orphaned abandoned derelict mines. According to Siegel and Veiga (2010: 275 in Chipangura, 2019), "… the study of the small-scale mining economy in developing countries is an emerging professional and academic field whose terrain is largely unmapped and hard edges still being determined".

Additionally, there has been a continued expansion of residential areas onto mining grounds in recent years, for example, through efforts to re-compact the city by bridging the north-south divide left by the mining belt. Many new areas are not yet well integrated into the urban fabric and are characterised by substandard infrastructure and poor service delivery (Winde and Stoch, 2010). Trangos and Bobbins (2018) suggest that the reprocessing of mine waste could assist in reconnecting the socially and economically fragmented city and address the socio-economic vulnerabilities underpinning GCR's unequal society. Thus, considering these lands for future development is pivotal and can be achieved by embracing active restoration, rehabilitation, and reclamation of post-mining landscapes (Festin et al., 2017). Moreover, Bobbins (2015) argues that effective restoration and reclamation efforts require the active involvement of the mining industry as well as a shift in the operational focus of mining companies where they shift from active mining to property development, allowing derelict land near mining waste or proclaimed mine lands to be reclaimed and redeveloped.

Several remedial approaches have been proposed to reuse and integrate the GCR's post-mining landscapes into the urban framework. In 2015, the Council for Scientific and Industrial Research (CSIR) came up with a proposal to assess the opportunity of creating stone paper from waste rubble and mine tailings found in Gauteng. Stone paper is a paper-like product that uses waste rubble or mine tailings for manufacturing stationery, leaflets, posters, books, magazines, bags, adhesives, plates and containers (Stafford et al., 2015; Kumar et al., 2020). This proposal to reuse mine waste follows the "blue economy" principle, premised on the notion that no waste should be wasted by designing innovative and sustainable recycling initiatives. Such innovations have been reported in several international studies (Haibin and Zhenling, 2010; Pauli, 2010; Smith-Godfrey, 2016) and local studies, such as Stafford et al. (2015). The advantage of using mine waste in making stone paper is that it reduces rehabilitation costs of previously mined and marginalised land, creates jobs and makes the rehabilitated land available for other developments. However, there are some challenges in reworking these affected pieces of land, especially in those areas where such pieces of land have been repurposed for disposal sites for municipal waste and sewage (Stafford et al., 2015).

Trangos and Bobbins (2018) argue that post-mining landscapes should not be merely treated as wastelands but should be considered spaces of considerable prospects with opportunities to regenerate urban environments. Therefore, the regeneration of these post-mining landscapes is expected to be accompanied by an endowment of economic, ecological, and social value to communities living close to abandoned mines along the Witwatersrand mining basin. Bobbins (2015) argues that while the land affected by these hazards may be dangerous, the strategic placement of mine residue areas provides an opportunity to remediate well-located land for future development close to the city centre. At the same time, MRAs may relieve the pressures on the natural environment by providing alternative positions for the densification of industries, other than pressurising the existing open spaces and green networks. Similarly, the extraction and treatment of AMD can provide potable water for future regional residents if adequately remediated, although evidence of such an initiative in Gauteng could not be located.

As such, a few critical rehabilitation efforts have been made in the recent past. For example, MRA remediation and new developments have been in Stormill, Robertville, NASREC, Aeroton, Ormonde, Crown, Selby, and Heriotdale. Once remediated, these areas provided opportunities in the form of much-needed residential space in the city (Simons and Karam, 2008). Furthermore, Bobbins (2015) argues that adopting a green infrastructure approach, such as introducing specific vegetation, can also reduce the seepages of acid mine drainage and the overall spread of contaminants into the surrounding land. Another example of how land characterised by mine dumps was converted into urban houses can be drawn from formal spatial developments of low-cost housing in Soweto between 1990 and 2000 to ease pressure and demand for land in Johannesburg (Turton et al., 2006). However, this has not been without its challenges, mainly owing to most tailings in the region being from gold mining and thought to be radioactive.

However, several hurdles still haunt rehabilitation efforts. Key concerns relate to the lack of funds to roll out remediation and treatment options and the existence of derelict and ownerless mines. The contaminated soil and water contain heavy metals and may be radioactive, thus toxic to humans, animals, and the ecology. Moreover, in some cases, these impacts worsen over time. For example, although the land area is relatively small, the effect of the mining hazards is significant regarding the pollution downstream, with suburbs such as Davidsonville, Fleurhof, and Riverlea facing major environmental health concerns directly (Benchmarks Foundation, 2017).

Another major challenge for the government is the abandonment of mines and mining waste by bankrupt mining companies[15]. In the DMR Annual Performance Plan for (2013/14), the government announced an internal programme in which thirty mining rehabilitation projects had been prioritised and funded by the government. This programme was expected to allow at least fifty ownerless and derelict mines to be rehabilitated yearly (Trangos and Bobbins, 2018). However, most of these plans did not materialise. Trangos and Bobbins (2018) argue that this is due to complicated and divided interests at the national level that diminish the incentive to rehabilitate ownerless and abandoned mines. This creates challenges at provincial and local levels where smaller projects fail due to a lack of interest and support from the national DMR. At the same time, the commercial mining sector also bears much responsibility for the current situation. However, this results from centuries of mining efforts by hundreds of companies, many of which no longer exist, while others continue their activities through subsidiaries. It is, therefore, impossible to hold them responsible for addressing these issues (McCarthy, 2010). It is important to note that mines now defunct have primarily funded the infrastructure Gauteng residents enjoy. As such, McCarthy (2010) suggests that the bulk of the bill must come from national budgets and existing mines that continue contributing to the problem.

2.6. MINING AND DEVELOPMENT IN GAUTENG

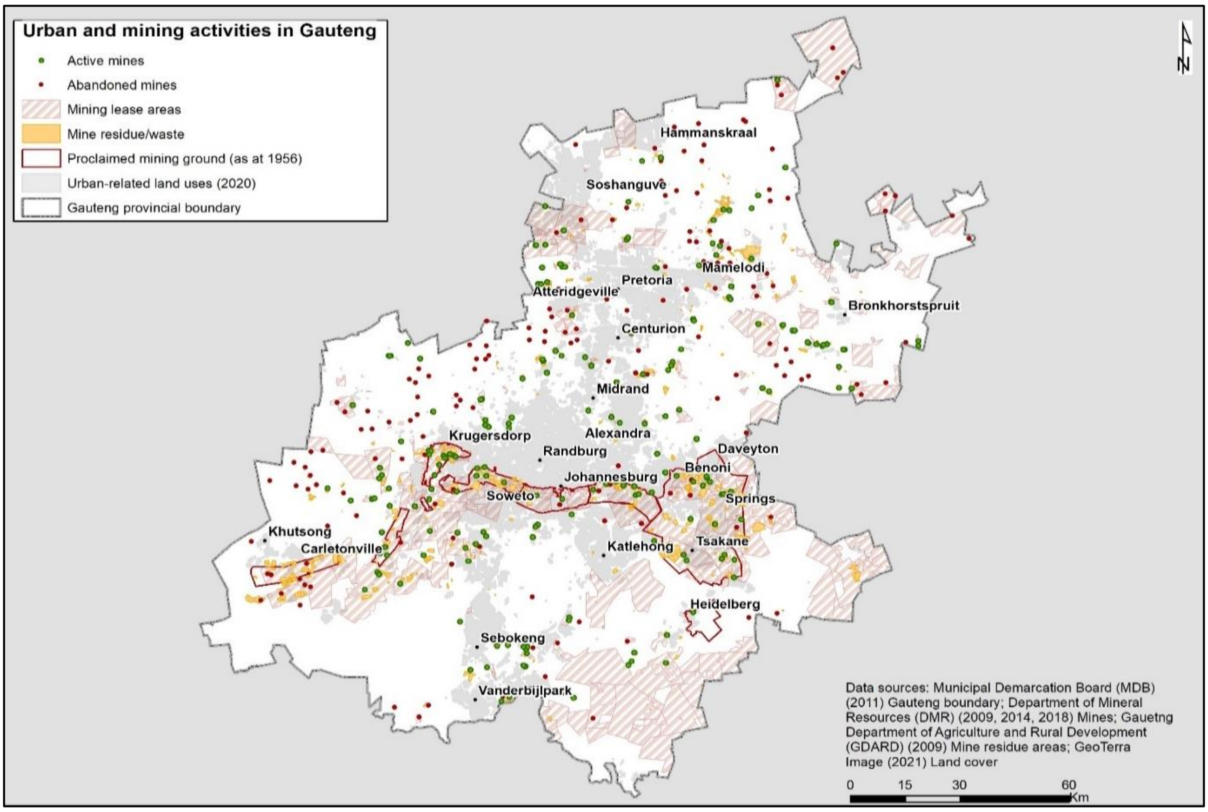
The influence of the mining sector on Gauteng over time is evident through the increased exploration of various minerals and commodities across the province. This shift occurred as the mining activities started moving further away from the initial mining grounds with the depletion of mineral reserves (Heath, 2009; Robb and Robb, 1998). Simultaneously, it led to the emergence of smaller mining towns and communities away from the traditional mining areas. Some of these mining towns have succumbed to the gradual decline of the South African mining industry, while others continue to thrive (Harrison and Zack, 2012; Fafchamps et al., 2017). Bryceson and MacKinnon (2012) have also referred to these cities and towns as 'mineralised urbanisation' spaces.

With the development and growth of Johannesburg as the core economic hub, prospective mine labour migrated from other provinces and countries, contributing to the development of an array of mining settlements and villages (Harrison and Zack, 2012). The Masters and Servants Act (15 of 1856) obligated rural inhabitants near mining towns to provide labour to these new mining towns, imposing

[15] According to the South African Auditor General (2009), there are approximately 6000 ownerless mines in Gauteng alone, which consequently become the responsibility of the government (Benchmarks Foundation, 2017).

compulsory cash taxes on males. This forced rural dwellers to seek employment in the neighbouring mines and supporting industries, further accelerating the influx of labourers to the emerging mining industry and establishing a mining camp in 1886. This, in turn, led to population growth in the Witwatersrand (Mubiwa, 2013). The influx of labour into neighbouring mine camps rapidly evolved them into village-type settlements as the demand for gold started declining, and new economic activities were introduced, eventually growing into towns, cities, metropolises, and finally, the Gauteng City-Region (GCR)[16] (Beavon, 2001; Bryceson and MacKinnon, 2012).

Map 7 shows that this region's urban and infrastructural development is centrally located at the province's core, radiating outwards on either side of the Witwatersrand belt. Today, this is also coincident with the location of formal residential areas (Khanyile, 2016; Rubin and Harrison, 2016). However, some parts of the mining belt are now characterised by informality (Rubin and Harrison, 2016; Marais et al., 2018).



Map 7: Urban and mining activities in Gauteng. Source: Author (2023).

The mining activities of the Witwatersrand, despite their declining contribution to the economy in the past three decades, have been the most significant catalyst for sustaining the infrastructure and influencing industrial development, rate of urban development and urban spatial patterns within the

[16] The agglomeration of Gauteng and surrounding urban areas (Mabin, 2013).

province (Cowey, 1994). As a result, 14.8% of the province is characterised by urban characteristics, comprising residential areas (9.5%), commercial and industrial areas (1.2%), institutions (0.8%) and utilities and other areas (0.7%) (GTI, 2020). However, a large acreage of prime Gauteng land is also characterised by mining or remnants of mining activities, which still significantly influence urban development trajectories.

2.7. SUMMARY OF THE CHAPTER

This chapter has introduced the Gauteng province as the smallest province in South Africa. The chapter discusses how the discovery of gold in 1886 was a significant turning point for the historical understanding of the province. This chapter introduced Gauteng as the fastest urbanising province in South Africa, discussing urbanisation in the country and Gauteng and further discussing how, despite urbanisation, the province is also characterised by mining activities and their resultant post-mining landscapes. The mining activities in the region were discussed, as well as the regulation of these landscapes and their negative externalities, particularly the environmental and socio-economic impacts of mining. The co-existence of urban and mining processes in the province is discussed, along with the reclamation and rehabilitation plans for the region to integrate these landscapes into the urban frame. The chapter ends with a discussion of the role that mining has played in the development of the province, which is presently characterised by a rich and diverse history, cultures, diversified economies and infrastructural development.

CHAPTER THREE: CONCEPTUAL AND THEORETICAL DEVELOPMENT

3.1. INTRODUCTION

This thesis integrates three main areas of knowledge relating to:

1. Assemblage theory;
2. Urban landscapes; and
3. Post-mining landscapes

This section provides a theoretical and thematic background that helps define the critical theory and literature guiding the thinking in this study. Although not formalised by Deleuze and Guattari (1987) as a theory, this thesis is guided by the *Assemblage theory*. According to Deleuze and Guattari (1987), a theory is a relay between practical fields to overcome barriers. In this sense, “assemblage theory’ (Deleuze and Guattari, 1987) will be employed in this chapter to traverse and bring together the two landscapes of interest, namely, urban and post-mining. These landscapes are characterised by historical relations, social power, tangible and intangible characteristics, change and complexity. Deleuze and Guattari’s (1987) ontology will be employed as a philosophical lens to help combine these concepts under a single framework and propose a unified vocabulary to understand and describe Gauteng and similar landscapes. The introduction of the two landscapes follows this, tracing the genealogy of ‘urban’ and ‘post-mining’ landscapes to critically evaluate and reflect on how they are currently understood and used in the regional context and how they have evolved.

3.2. ASSEMBLAGE THEORY

This section discusses the main guiding theory applied within this research study and is divided into three parts. The first part gives an overview of assemblage theory, particularly its establishment and application by other scholars. The second part discusses the key qualities of assemblage theory. The third part discusses the dimensions of assemblage theory.

3.2.1. Overview of assemblage theory

Based on a relational ontology, assemblage theory expands upon the existing body of ontological knowledge (Anderson, 2012 in Woods et al., 2021). While Deleuze and Guattari (1987) pioneered the concept of assemblage theory, they never formalised it as a theory but instead used it ad hoc in their research to describe relationships and connectivity amongst elements. Specifically, Deleuze and Guattari’s work uses the term ‘constellations’ when referring to an assemblage, which entails constituent parts. Their work provides a concept for describing the parts and relationships between them, where parts need to yield a whole with properties of its own and be reducible to qualify as an assemblage (McGowan, 2019).

In *A Thousand Plateaus: Capitalism, Schizophrenia (1987),* Deleuze and Guattari developed assemblage theory by incorporating systems theory, encompassing social, linguistic, and philosophical systems. They view the world as composed of rhizomatically interconnected elements, although not all connections are visible. The theory has been translated as "agencement," meaning "putting together" or "arranging," and as "assemblage" by Massumi in the late 1980s (Brenner et al., 2011). Assemblage theory considers the notions of heterogeneity based on Deleuze's philosophy of elements being in a state of becoming, providing a popular theoretical foundation for understanding and working with complex dynamic systems (McGowan, 2019).

Since its inception, assemblage theory has been interpreted and utilised in various ways, such as in the context of networks, multiplicity, emergence, and indeterminacy. There is no one right way to adopt this term, as demonstrated by various scholars (Wise, 2005; De Landa, 2006; Dovey, 2010; Anderson and McFarlane, 2011a; Kamalipour and Peimani, 2015; McGowan, 2019). De Landa (2006) is among the leading interpreters of this theory, using it to examine the complexity of society. De Landa also proposes that space is composed of diverse elements and can only be understood by considering the role of these heterogeneous components in shaping the emergence of space.

Similarly, Wise (2005) views assemblage as a process of reordering and organisation. Other scholars like Massey (2005), Dovey (2010), and Kamalipour and Peimani (2015) argue that assemblages are not pre-existing and are instead constantly being constructed through the interplay of different social and material phenomena, power dynamics, exploitation, ideologies, and inequalities within a space. As such, assemblage theory emphasises the importance of heterogeneity, diversity, and connections between elements instead of differences. Moreover, assemblage theory operates at multiple scales and can examine urban issues and relationships at various levels (Wise, 2005; Kamalipour and Peimani, 2015; McGowan, 2019). Visual aids such as diagrams illustrate the relationships between the various elements of space. These visualisations can provide insights into the spatial manifestation of different city interactions (De Landa, 2005; Kamalipour et al., 2014).

Assemblage theory offers a unique way of understanding change in complex systems like cities by highlighting the dynamic nature of relationships between heterogeneous elements. De Landa (2006: 132) notes the importance of focussing on inter-relationships between the heterogeneous components of a phenomenon such as a city, saying:

> "Today we know that neither nature nor cities are in harmony, that is, in a static state of equilibrium. Both natural and social structures emerge in a complex dynamic process, which may involve changes from one stable state to another, from a steady stable state to a cyclic

> stable state, to a more chaotic stable state. Cities are unstable eco-systems far from equilibrium."

Assemblage theory offers many concepts for comprehending, expressing, and adapting to complex changes. According to De Landa (2006), assemblages are governed by the principle of multiplicity and can exist simultaneously in a stable and constant state of becoming. This is because Deleuze and Guattari's ontology (1987) is based on the perpetual evolution of entities that are different from their parts, the rejection of the parts' independent existence, the ongoing interaction of natural and biological forces that never reach stability, and the changing relationships between bodies (McGowan, 2019). The concepts of difference and evolution are understood through ideas that explain the circumstances, situations, and timing of events, how things are, how they change, and how spatial elements occupy space (Anderson et al., 2012). Section *3.2.2.* discusses the essential qualities of assemblages based on assemblage theory.

3.2.2. Key qualities of assemblages

Assemblages are complete entities that arise through the interaction of their constituent parts. The source of these entities is their heterogeneity, diversity, relations and linkages, where the driving force of these entities is not their unity but rather their differences (Deleuze and Guattari, 1987; De Landa, 2005; Rutzou and Elder-Vass, 2019). According to De Landa (2006), assemblages can be part of larger assemblages in a non-hierarchical relationship, where components from different assemblages can influence one another. For instance, they can both restrict and provide opportunities to their components. The emergence, relationality, and self-organisation principles guide the influence between assemblages and constituting parts (Spies and Alff, 2020). As such, the significance of assemblage theory in comprehending complex systems, such as urban contexts and their social-environmental transformations, becomes apparent. Importantly, assemblages are not predetermined parts randomly assembled but constellations of diverse components (including territories, structures, individuals, and identities) that come together and create new modes of functioning (McGowan, 2019). Thus, an assemblage can drive the amalgamation, organisation, and operation of institutions, spaces, and ecologies (De Landa, 2006, 2011).

All these "structures" hold relevance in understanding urban and post-mining landscapes. This thesis specifically focuses on the co-existence of urban and post-mining landscapes in Gauteng and the integration of their distinctive characteristics. Hence, the concepts formulated by Deleuze and Guattari (as discussed by De Landa, 2005, 2006; McFarlane, 2009; Brenner et al., 2011; De Landa, 2011; Brenner et al., 2013; Peimani, 2015; Dovey and Pafka, 2018) assume central importance in this thesis, serving as a theoretical and philosophical framework for investigating the socio-environmental attributes of the landscapes under examination.

McFarlane (2011a, 2011b), in their exploration of the relationship between assemblages and social-environmental systems, proposes that assemblages can be viewed as constructing urbanism rather than being static outcomes (McFarlane, 2011a). They advocate for adopting "assemblage thinking" to conceptualise the city, emphasizing that it is not a fixed entity but an ongoing and dynamic process of "making urbanism" through historical and potential relationships. From this perspective, an assemblage is not defined by the properties of its components but by the interactions and collaborative functioning of these elements, which contribute to the stabilizing or destabilizing dynamics of the urban system (McFarlane, 2011b).

The assemblages examined in this thesis, namely urban and post-mining landscapes, are socio-material assemblages composed and defined by people as actors and the urban and post-mining environments as territories. The components characterising both landscapes operate across various scales, similar to assemblages, which can be regarded as 'abstract machines' embodying a broader array of functions (Wise, 2005). At the same time, these landscapes are constantly changing, similar to assemblages that are continuously emerging and becoming, with some parts existing before the whole and the whole generating other parts, necessitating a 'multiscale' explanation (De Landa, 2006; Kamalipour and Peimani, 2015).

It is also essential to consider that emergent wholes are characterised by dynamic relations rather than synthetic totality and organisation rather than organisms. This implies that the autonomy of diverse parts is not forfeited when they come together to form an assemblage, even if the assemblage disintegrates (Brown, 2020). De Landa (2005) argues that parts losing their identity when fused into a whole contradicted evidence observed in communities, where individuals can join an assemblage, retain their identity, and depart from the assemblage while maintaining their individuality. This research demonstrates a similar phenomenon through the distinct characteristics of the post-mining and urban landscapes co-existing within the same space, forming a post-mining urban landscape.

3.2.3 Dimensions of Assemblages

With an understanding of the definition of assemblages, this thesis is interested in how the two landscapes under study are interlinked. Deleuze and Guattari (1987) identify two key dimensions describing assemblages. The first dimension defines the roles of entities in an assemblage. In contrast, the second describes how assemblages may change and refers to this process as territorialisation, deterritorialisation, and reterritorialisation. In their description of the first dimension, i.e. the roles of entities in an assemblage, Deleuze and Guattari (1987) state that the role of an entity is determined from one dimension or role, be it material on the one hand or purely expressive on the other (De Landa, 2006; Dovey, 2010; Farias, 2010; Kamalipour and Peimani, 2015; McGowan, 2019). McGowan (2019) says that a given component may play a mixture of material and expressive roles by exercising different capacities. For example, a component can engage with other parts of an assemblage at the molecular level while at the same time setting as a source of limitations and opportunities to all assemblage components. This can be seen when a community constrains its members by enforcing communal norms (Woods et al., 2012).

Similarly, De Landa (2006) argues that assemblage components can practice or assume roles in different capacities due to assemblage components not having fixed identities or functions within assemblages. The implication, therefore, is that assemblage components can have relationships with multiple components (Woods et al., 2012). These components can be heterogeneous, reserving their autonomy while being affected by the whole (Brown, 2020). While the first dimension opposes and connects materiality to formal expression, both distinguish and connect flows and interactions of bodies and things in space to expressions of meanings (Dovey, 2010).

Moreover, Dovey (2010) argues that the second dimension defines the processes in which assemblage components become involved, stabilizing the identity of an assemblage by increasing its degree of internal homogeneity or destabilizing it. Similarly, Wise (2005) and De Landa (2005) argue that assemblages can be made and unmade through stabilisation (territorialisation) and destabilisation (deterritorialisation) or reterritorialisation. According to Dovey (2010), these processes are concerned with the formulation and erasure of assemblages.

According to De Landa (2011), territorialisation is mainly concerned with the structure of the assemblage and the relations that shape it. Deleuze and Guattari (1987) argue that assemblages at their core are territorial, which can be spatial, non-spatial and highly territorialised. De Landa (2011) argues that there is also reterritorialisation, where assemblage components are more rigid (McGowan, 2019). Firm boundaries characterise these territorialised assemblages, accompanied by strong homogeneity, limiting an assemblage's dynamism (Woods et al., 2012). At the same time, according to De Landa (2006), deterritorialised assemblages are characterised by heterogeneous components and greater mixing and interaction between assemblage components. Strong assemblages have porous borders and internal heterogeneity and undergo cycles of territorialisation, deterritorialisation, and reterritorialisation (Woods et al., 2012; Buchanan and Parr, 2006 in Kamalipour and Peimani, 2015).

However, even though assemblage thinking allows for recognizing various relations in urban spaces, it has critics. Some theory critiques argue that it does not consider that spatial relations are changing with rapid urbanisation rates and urbanisation processes. For example, significant changes in the geographies of urbanisation blur the lines between urban and rural (Brenner, 2013). The evolving positionalities of cities and urban spaces question the applicability and the adequacy of concepts such as assemblage theory, arguing that they are using territorial-centric methodologies rooted in outdated research agendas and so fail to grasp the complexities of urban spaces in the present (Brenner et al. 2011). In light of this, some research argues that the dynamic nature of urban spaces requires a change in the understanding of urban spaces (Brenner et al., 2011) and a more explicit distinction between urban and non-urban spaces (Harvey, 1976; Castells, 1977; Harvey, 1989). In addition, some other studies (e.g. Jervis, 2016) argue that urban research should move from defining characteristics of urban as they take different forms based on different contexts and that efforts should focus on understanding the interactions and processes defining urban spaces. Additionally, despite its apparent value, the actual application of assemblage theory to urban studies (in theory or practice) is limited. This is often attributed to the relatively complex nature of the theory, which has since been interpreted into a multitude of approaches to assemblage thinking, including assemblage theory, actor-network theory, and non-representational theory (Thrift, 2004; Latour, 2005; De Landa, 2006; Buchanan, 2017).

Consequently, there has also been a rise in alternative urban theories meant to address this gap, such as critical urban theory, which Brenner (2009) and McFarlane (2011a) suggest stems from assemblage theory and political economy thinking. Research informed by critical urban theory argues that cities are spaces resulting from short-term and long-term (historical) social power relations, ideologies, injustices, exploitations, and equities in cities. Similarly, Brenner et al. (2011) argue that assemblage theory ignores the context and the other broader place-specific and general structures in place. Moreover, Farias (2011) argues that assemblage thinking favours more empirical than theoretical analysis as it incorporates agency and arrangement.

Nevertheless, the work of Deleuze, Guattari, and De Landa, as presented in their writings and subsequent studies (McFarlane, 2009; Brenner et al., 2011; Brenner et al., 2013; Kamalipour and Peimani, 2015; Dovey and Pafka, 2018), is critical to this thesis, both in terms of providing a philosophical lens and a theory. This thesis applies assemblage theory in a new way, specifically to propose the integration of Gauteng's post-mining and urban landscapes, demonstrating an unclear boundary between the two. The following section discusses the history of the concept and examines post-mining and urban landscapes.

3.3. THE QUESTION OF THE LANDSCAPE

The concept of the landscape emerged during the Renaissance and the rise of modernity in 15th-century Europe (Cosgrove, 1984; Antrop, 2013; Berque, 2013). It is a complex notion that arises from the interaction of humans with the environment, culture, politics, and academia, leading researchers to employ different approaches in their understanding and discussions of the landscape (Swaffield, 1991; Angelstam et al., 2013; Plienenger et al., 2015; Keshtkaran, 2019).

Scholars propose varied interpretations of the landscape (Johnson, 2007). According to Rodaway's compilation, one early description comes from Relph (1976: 122), stating that "the landscape is not merely an aesthetic backdrop to life; instead, it is a setting that both expresses and influences cultural attitudes and activities. Significant changes to landscapes are not possible without major shifts in social attitudes. Therefore, landscapes always carry meanings from how and why we perceive them."

Another definition, not included in Rodaway's list, by Crumley and Marquardt (1990: 73), describes the landscape as "the spatial manifestation of the relations between humans and their environment. It includes the study of population concentrations of all sizes, from isolated farms to metropolises, as well as the roads connecting them." This notion is further elaborated on by Folke (2016), stating that landscapes are socio-ecological systems where humans and nature interact and are intertwined.

As such, the term "landscape" is highly complex, and considerable debates exist regarding its understanding. Landscape research is commonly divided into two traditions: a) a biophysical approach to landscape characterisation rooted in the natural sciences, and b) a landscape character assessment tradition rooted in arts and humanities (Antrop, 2000; Brabyn, 2009). Physical geographers and landscape ecologists primarily adopt the former, defining landscape units as tangible areas on the earth's surface. Landscapes are composed of natural elements like mountains, waters, fields, and plants, and artificial elements encompassing buildings, streets, structures, squares, green spaces, gardens, and environmental enhancements (Cosgrove, 1984; Wang et al., 2012; Marot and Harfst, 2021). This tradition considers the physical manifestation of the interface between nature and society (Burgi et al., 2004). This tradition aligns with the German meaning of the word "Landschaft," which describes the physical content of an area (Antrop and Van Eetvelde, 2017). This relates to how the landscape exists within the territorial system that gives rise to it, exhibiting multiple functional and hierarchical structures and characteristics. These contrasting definitions result in various perspectives on the challenges associated with human and natural interactions with the environment, such as climate change, social alienation, environmental degradation, biodiversity loss, and heritage destruction. Furthermore, there is an ongoing debate about the origins and intended use of the concept at its inception.

The term has evolved, as depicted in Figure 6, which outlines the concept's evolution. Initially, it served as a foundational aspect of geography, providing systematic descriptions and often associated with vast land areas or well-defined territories visually characterised by distinct physical features (Tuan, 1979; Porteous, 1990; Swaffield, 1991; Antrop, 2013). The complex patterns that define landscapes have led to new opportunities for understanding them and changes at different scales. For example, geography has focused on the morphological analysis of landscapes, examining their spatial organisation, such as regions, relative locations, orientations, or elevations (Hoskins, 1977 in Johnson, 2007). While most uses of the term "landscape" emphasise its morphological analysis, particularly the spatial arrangement of an area, some interpretations view it in a political context (Denier et al., 2015). After World War II, landscape research primarily concentrated on classifying landscapes, including their chronology, typology, and genesis, to establish regional identities (Antrop and Van Eetvelde, 2000; Krause, 2001; Jensen, 2005; Antrop, 2013). Although the initial conceptions of the word "landscape" have been abandoned, the practice remains to consider the landscape as a reference point, concept, or stage for examining phenomena or human interactions with the physical environment (Palka, 1995; Antrop, 2013; Gerber and Hess, 2017), making it applicable to several disciplines (Antrop, 2013).

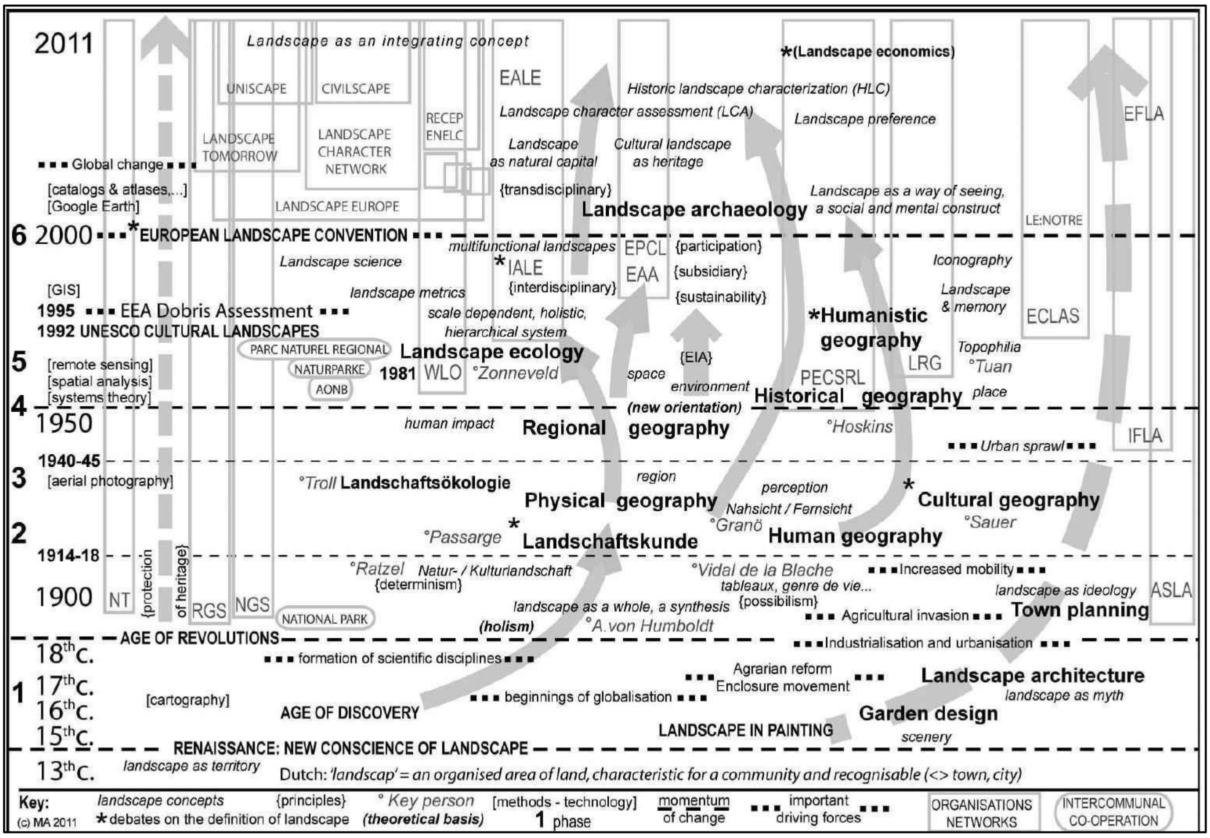


Figure 6: Evolution of the conceptualisation of the landscape. Source: Antrop (2013).

As a concept, it is multi-layered and broad, including various objective, subjective, collective, and individual issues (Antrop, 2000; Naveh, 2000; Crow et al., 2006; Naveh, 2007). It cannot be limited to a collaborative effort between disciplines such as geography, architecture, sociology, and ecology. The landscape comprises physical reality and other dimensions, such as social, mental, and cultural properties (Doevendans et al., 2007; Kaplan, 2009). The word "landscape" has multiple meanings and practical applications and is translated into several languages. Some scholars have defined landscapes as an "identifiable tract of land" (Cosgrove, 1984: 16). Others have chosen more encompassing definitions, focusing on the physical makeup (Zonneveld, 1995; Krause, 2001; Lörzing, 2001; Thomas, 2001; Donadieau, 2013; Opdam et al., 2018 and Marot and Harfst, 2021), use and functionality (Bender, 2002; Willemen et al., 2008) or as a system in movement or progress (Appleton, 1975; Kuitert, 2013;

Lowenthal, 2007; Karro et al., 2014 in Watson, 2020). The landscape describes the spaces where people make their homes, work, live and dream. Similarly, through an alternative lens, others have resorted to defining landscapes as natural, cultural landscapes (Antrop, 2013), historical, or physical representations. Quite interestingly, despite the varying definitions, several themes emerge from all these definitions of landscapes, such as human perception, outdoors, natural and cultural mixing and change, and the notion of a passage of time (Bender, 2002; Palang, 2010). On time, Roymans et al. (2009 in Watson, 2020) and Marcucci (2000) state that landscapes are transformative and sequential and reflect past and present practices. Meinig (1979) and Palang (2010) further note that landscapes are continuous and, therefore, characterised by transitional boundaries.

A further theme emerging from the broad literature is that landscapes are unnatural and constructed spaces resulting from accumulating activities, relationships, interactions and disconnections over time (Corner, 1992; Gosden and Head, 1994; Karro et al., 2014 in Watson, 2020), much like the post-mining and urban landscapes investigated in this study. Many authors have used Deleuze and Guattari's work to understand landscapes, including Brenner et al. (2011) and Muminovic (2015). While this thesis references some of this work, these works are primarily for indicating the applicability of landscape as a concept of study across several disciplines and drawing relations with the theoretical base of this thesis.

This thesis adopts the definition of the landscape from the European Convention on Landscape (Council of Europe, 2000: 9), which considers it as "an area, as perceived by residents or visitors, that changes over time due to the influence of both natural forces and human activities". Understood in this sense, which, at its most basic, refers to a spatial unit characterised by region-specific elements, subjects, and processes reflecting the immobile structure (Krause, 2001; Maciocco, 2008) and can be considered a conceptual and physical assemblage. On the one hand, the concept of the landscape is synergistic, multi-disciplinary, has multiple meanings and therefore challenges researchers and individuals to think differently about their surroundings (Farina, 2000; Howard et al., 2013). On the other hand, the landscape is an assemblage characterised by various physical components, such as rocks and rivers, and the interaction between its natural and human systems (Barad, 2007). Therefore, this thesis considers the landscape as a unit of study and integrative concept of different landscape characteristics, although noting its complexities, using the example of the complex relationship between mining and urbanisation in Gauteng, South Africa.

3.3.1. Landscape research studies

Due to the intricate nature of landscape conceptualisation, there has been a growing focus on landscape character studies. These studies have garnered increasing attention from planners, researchers, and decision-makers in recent years, leading to continually evolving research outcomes (Carlier et al., 2021). Landscape character studies play a crucial role in understanding the essence of landscapes and aiding decision-making processes. With a long history, these studies primarily revolve around various perspectives. One key aspect is the identification and classification of landscape characters (Zhuang et al., 2022). Such classifications hold significance in landscape research as they provide a framework for researchers to communicate and compare their work (Brabyn, 1996).

Given the multidisciplinary nature of landscape research, multiple systems and methods exist for identifying and classifying landscapes. These approaches are rooted in various traditions and disciplines such as history, geography, geology, ecology, geomorphology, landscape architecture, and archaeology. Depending on their scientific background, these systems and methods emphasise different aspects of the landscape and address variations in landscape properties at various spatial and temporal scales (Simensen et al., 2018). However, all these classification approaches are artificial, as they draw boundaries in a continuous environment characterised by constant changes in the composition of landscape elements. As a result, various characterisation methods have been introduced over the years, with varying levels of accuracy, suggesting that landscape classifications are not inherently right or wrong but rather appropriate or unsuitable depending on specific contexts. Therefore, the choice of characterisation method and spatial resolution should be based on user needs and the availability of comprehensive area coverage for the study area (Simensen et al., 2018).

Among the existing landscape characterisation methods, the Landscape Character Assessment (LCA) is the most widely used in landscape character studies. Developed in the United Kingdom (UK) and France in the 1990s, LCA aims to identify, classify, and understand landscapes and people's perceptions as part of spatial planning and development frameworks (Van Eetvelde and Antrop, 2009). While many perception-based approaches explicitly focus on identifying landscape values, LCA differentiates between two stages: the relatively value-free process of characterisation and the subsequent judgment and value assessment based on knowledge of landscape character (Simensen et al., 2018). Consequently, landscape characterisations offer a practical assessment to identify distinct characteristics that can be applied in landscape planning, conservation, and management (Zhuang et al., 2022).

In the LCA framework, landscape character types and landscape character areas are distinguished. Landscape character refers to the unique aesthetic features that differentiate one scene from another within specific time and space ranges, expressing the distinct aesthetic qualities of landscapes (Wang et al., 2012). On the other hand, landscape character types represent relatively homogeneous landscapes with similar combinations of geology, topography, drainage patterns, vegetation, and historical land use and settlement patterns (Swanwick, 2002 in Van Eetvelde and Antrop, 2009). Meanwhile, landscape character areas are defined as discrete geographical areas of a particular landscape type, each possessing its distinct character and identity while sharing general characteristics with other areas. This distinction is reflected in their nomenclature: landscape character types have generic names like moorland plateau and river valley, whereas landscape character areas are named after specific places. These character types and areas are defined at different hierarchical scale levels, aligning with the hierarchical approach of the holistic method (Van Eetvelde and Antrop, 2009).

However, starting from the 1970s, there has been an increasing demand for a new holistic and inclusive approach to understanding landscapes. Landscape characterisation and related studies emerged in the UK, expanding beyond the complete protection and management of the most valuable landscapes (Dabaut and Carrer, 2020). Adopting a holistic approach to defining landscape units allows for integrating and interpreting physical and cultural landscape components based on spatial configurations of landscape types (Van Eetvelde and Antrop, 2009). Nevertheless, there is no singular preferable holistic concept for planning landscapes universally. Consequently, only partial attempts have been made thus far to combine physical-geographical and human-geographical perspectives (Dabaut and Carrer, 2020). Groom et al. (2006) reviewed several European landscape classifications and concluded that most classifications were expert-driven and developed top-down. Automated derivations of landscape character types and areas were limited and often required expert interpretation of the computerised results.

This research recognises the need for a holistic understanding and conceptualisation of the Gauteng landscape, encompassing all its characteristics, including its seemingly contrasting mining and urban characteristics. It aims to achieve a more comprehensive understanding of post-mining and urban landscapes and their associated characteristics. Additionally, it considers how these characteristics can be integrated. The following sections discuss the two landscapes under investigation.

3.3.1.1. Urbanisation and the urban landscape

The term "urban landscape" originated during the late 19th century with Frederick Olmsted, the renowned landscape architect often referred to as the father of landscape architecture (Olmsted, 1863, as cited in Kreshtkaran, 2019). The concept of the urban landscape has long been intertwined with the city itself; therefore, much of the literature on the urban encompasses discussions about cities. Consequently, understanding the genealogy of this concept requires exploring disciplines such as urbanism, urban design, architecture and landscapes, urban planning, geography, and geology (Kreshtkaran, 2019).

The urban landscape is a complex concept that arises from the interaction between humans and the environment, influenced by society, culture, and economy (Kaymaz, 2013). Similarly, Lindholm (2012) argues that the urban landscape serves as a medium through which individuals comprehend the city they inhabit. Urban landscapes are human-made environments characterised by physical, cultural, and spiritual dimensions (Zhang, 2014). Golkar (2008) further highlights that urban landscapes encompass various aspects, including urban design, urban planning, urban management, and the recognition of individual goals and responsibilities. Consequently, urban landscapes exhibit a diverse range of characteristics (Lingfeng and Xilong, 2009) and can carry different meanings depending on disciplinary perspectives, often grounded in fundamental dichotomies like "urban-rural", "constructed-indigenous," or "cultural-natural" (Lindholm, 2012).

The term "urban landscape" consists of two words, "city" and "landscape," both of which carry contradictory meanings (Kreshtkaran, 2019). Studies by Cullen (1961), Golkar (2008) and Kreshtkaran (2019) have revealed that these meanings vary depending on interpretations of the city and landscape as separate concepts and the researcher's approach, which can be objective or subjective. Consequently, due to these diverse understandings, the urban landscape can be viewed as a paradigm encompassing concepts, theories, rules, patterns, tools, and practices. It can be approached through four main perspectives aimed at comprehending the urban landscape: the Artistic, Functional, Perceptual / contextual, and, more recently, the Sustainable approach (adapted from Kreshtkaran, 2019, Figure 7).

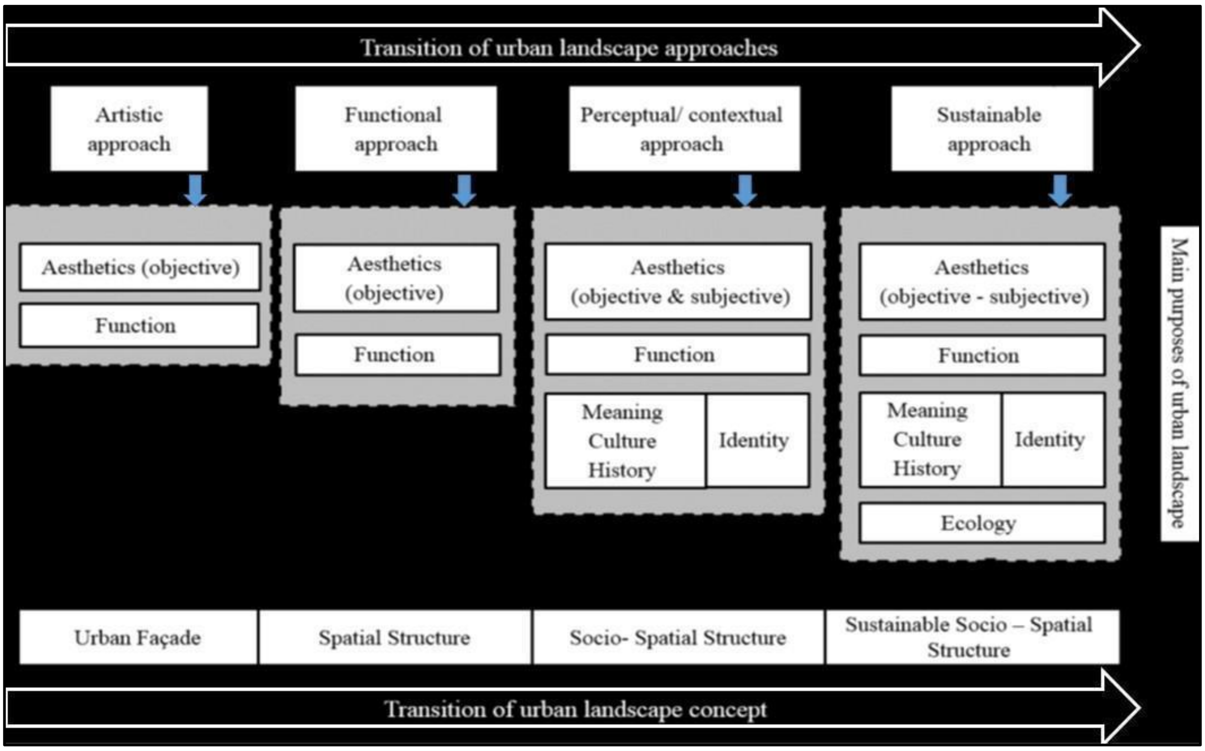


Figure 7: Genealogy of the concept of the urban landscape. Source: Kretshkaran (2019).

In Figure 7, the evolution of the concept of the urban landscape is depicted, highlighting different approaches theorists use to describe and understand it. Initially, theorists such as Sitte (1945) and Gibberd (1970) adopted an Artistic approach where the aesthetics of the urban landscape held paramount importance for urban planners and practitioners. The urban facade received significant attention, while the function was considered secondary. On the other hand, theorists like Le Corbusier

(1920 in Kreshtkaran, 2019) and others embraced a Functional approach, giving less importance to the urban facade and focusing more on functionality, standardisation, and effective urban planning. Le Corbusier proposed four main areas for a city: residential, industrial, commercial, and transportation infrastructure. This Functional approach, rooted in architectural and urban planning traditions, examined the physical aspects of built infrastructure within urban landscapes to evaluate their liveability (Stokes and Seto, 2019).

As the concept of urban landscapes evolved, some theorists, including Lynch (1960) and Kaplan (2009), adopted a Perceptual or Contextual approach. This approach moved away from a conservative understanding of the urban landscape and placed greater emphasis on socio-spatial structures and historical and cultural references. Lynch (1960) introduced the idea that the city is not just a collection of individuals and their social amenities but an integral part of the social process involving its inhabitants. He described the urban landscape as landmarks and nodes, edges and paths, and areas and buildings, all contributing to creating liveable public spaces. The Perceptual or Contextual approach also highlights the role of urban places in fostering social diversity and ethnic differences, leading to either unification or differentiation among the people of a region or their differentiation from others (Kruit and Hendricks, 2004 in Kreshtkaran, 2019).

By the 1970s, the sustainability-oriented approach gained prominence in describing urban landscapes. While still embracing a less objective perspective, this approach emphasised the environmental role of urban landscapes and the need for sustainable socio-spatial structures. The work of theorists like McHarg and Mumford (1969) exemplified this approach. Since the introduction of sustainability by the World Commission on Environment and Development in 1987, this approach has greatly influenced recent research on related topics (Stokes and Seto, 2019).

The concept of urban landscapes is multidisciplinary, encompassing various sciences and disciplines. Liu and Lin (2014) define "urban land" as a metropolitan area within a defined geographical or administrative boundary, including towns, cities, and suburbs. Urban areas are characterised by high levels of development and a dense concentration of human-made structures such as houses, commercial buildings, roads, bridges, and railways (Bidandi and Williams, 2020). Urban areas can be defined based on three dimensions: population size, population density, and building structure (Wu, 2014). However, urbanisation processes in Western and African countries differ significantly due to contrasting development trajectories (Bryceson and MacKinnon, 2012). Urbanisation in this context is still primarily characterised by poor governance, which contributes to the proliferation of informal settlements and sprawl, urban primacy[17] and challenges to provide basic urban services (Guneralp et al.

[17] Urban primacy refers to the process where one city is characterised by population densities, governance structures and political powers and economic activities that far surpass the next largest city (Guneralp et al. 2017).)

2017). Moreover, urbanisation in African contexts is still largely unplanned and has been exacerbated by colonialism and apartheid legacies in the South African context, which have contributed to weaker planning systems (Parnell and Pieterse, 2014; Ruhiiga, 2014). Therefore, a broad genealogy of the concept does not explicitly address how these definitions of urban landscapes manifest in the African and South African context, considering the country's history of apartheid.

3.3.1.2. From mining and industrialisation to post-mining landscapes

Two main land uses are associated with mining: the natural landscape before extracting mineral resources and the post-mining landscape that emerges after extraction (Lorandelle and Haase, 2012). Apart from the natural landscape transformation, these landscapes can have various environmental impacts, including topsoil destruction, erosion, sedimentation during storms, and soil contamination from hazardous substances (Kuter, 2013). Additionally, conflicts may arise in post-mining landscapes due to the degradation of the natural landscape and its cultural values, exploitation of indigenous groups, disputes over access to natural resources, conflicts with other land uses such as forestry, and social and environmental impact assessments (Bryant and Bailey, 1997; Horowitz, 2010; Burton et al., 2012; Kronenberg, 2013; Spiegel, 2017).

The mining life cycle is typically divided into five phases: exploration, site design and construction, operational mining, final closure and decommissioning and post-mining (post-closure) (International Council on Mining and Metals, 2008 in Watson, 2020). The post-mining phase, often the least understood of the three, refers to the open spaces, degraded green areas, or abandoned open-cast mines after mining activities conclude (Marot and Harfst, 2021). In the past, the mining industry primarily focused on the first three phases of the cycle, as they were the most profitable in the market. As a result, once mineral reserves were depleted or deemed unprofitable, mines were often abandoned, leaving behind degraded post-mining landscapes. Historically, little consideration was given to the potential environmental and social impacts of mining, and responsible mining entities faced minimal repercussions for their actions (Kivinen, 2017; Kretshmann, 2018). Consequently, post-mining sites frequently contain varying levels of toxic mine waste.

Numerous scholars have examined the outcomes of structural changes in old industrialised regions worldwide, with mining industries often standing out due to their significant physical impacts on landscapes and townscapes (Hassink and Shin, 2005; Morgan, 2013; Bungart and Hüttl, 2001; Marot, 2006; Böhm et al., 2011; Fischer and Stranz, 2011). Post-mining landscapes differ considerably from pre-mining landscapes in terms of surface structure, resource availability, and settlement patterns (Larondelle and Haase, 2012), presenting environmental quality challenges for local communities. Therefore, the literature often describes post-mining landscapes based on their resulting environmental impacts and pollution, such as acid mine drainage, which is characterised by the yellowish colour observed in many rivers across Gauteng (Kuter, 2013). Socio-economic challenges also characterise these landscapes, and conflicts with other land uses can arise, especially without adequate post-mining or mine closure strategies (Horowitz, 2009; Burton et al., 2012; Kronenberg, 2013; Spiegel, 2017).

The implementation of mine closures varies depending on the specific area and initial mining activities. Mine closure practices initially developed in the 1970s in countries with advanced economies and mature mining industries, such as Canada, Australia, and the United States of America. More recently, mine closure regulations have been influenced by sustainability considerations, emphasizing the need for mining operations to be sustainable and considerate of all phases of the mining life cycle, along with their associated economic, societal, and environmental impacts (United Nations Development Programme (UNDP), 2018; Asr et al., 2019; Burton et al., 2012). However, since mining inevitably entails some degree of impact, efforts must be made to minimise negative consequences (Kretshmann, 2018). This realisation has led to increased research and changes in the governance of post-mining landscapes. Studies now examine these landscapes' technical, ecological, and social dimensions to restore and stabilise them, aiming to approximate their pre-mining state and provide new opportunities for future land use (Limpitlaw and Briel, 2014).

While much of the literature on post-mining landscapes focuses on the technical aspects of rehabilitation, such as water retention, biomass testing, soil reclamation, and geothermal conversion, some argue that the use of these landscapes can lead to stigmatisation and neglect, as development tends to move away from such areas (Berger, 2006). However, other studies highlight the opportunities for urban regeneration and the understanding of spatial and cultural development presented by these landscapes (Berger, 2006; Esterhuysen et al., 2018; Bobbins and Trangos, 2018). Despite the growing interest in the reclamation of post-mining landscapes, their management remains challenging, as the methods employed depend on the characteristics of the mining activities (Kuter, 2013; Hattingh, 2018). Furthermore, even with rehabilitation efforts, the rehabilitated post-mining landscape remains distinct from the pre-mining landscape in terms of surface, resource availability, settlement patterns, and aesthetic and visual representation, which can significantly influence how these landscapes are perceived (Lorandelle and Haase, 2012; Sklenicka and Kasparova, 2008; Svobodova, 2012; Kivinen et al., 2018).

3.3.1.3. Mining activity and urbanisation

While mining and urban landscapes often conflict, some mining activities may result in urbanisation processes. Urbanisation driven by mining activities manifests in several ways. Bryceson and MacKinnon (2012) divide urbanisation from mining activities into industrial centres and settlements. On the one hand, industrial areas maintain the same commercial activities and have little economic heterogeneity (Bryceson and MacKinnon, 2012). On the other hand, mining settlements are further broken down into cities, communities or towns. Mining cities, while dominated by mining and extractive industries, often develop their financial and entrepreneurial capacity and persist despite changes in mining dynamics (Bryceson and MacKinnon, 2012; Martinez-Fernandez et al., 2012). Examples of such cities include San Francisco, which benefitted the most from the Californian gold rush of 1848 and had transformed into a burgeoning town by 1853 (Bryceson and MacKinnon, 2012) and Johannesburg, which capitalised on the mining activities of the Witwatersrand (Harrison and Zack, 2012). Mining communities or towns are mainly located at the periphery of economic and metropolitan areas and are characterised by housing for mining labour located adjacent to the mining activities (Martinez-Fernandez et al., 2012). These areas heavily depend on the mining activities that brought them to existence. They often do not develop their own financial or entrepreneurial capacity and, therefore, do not survive past the discontinuation of mining activities (Fafchamps et al., 2017).

However, Bryceson and MacKinnon (2012) argue that a new kind of 'mineralised urbanisation' also results from mining activities. These mineralised urbanisations result from mining booms and mining-led migration to certain places, which have, over time, left lasting implications for the national economies and urban development trajectories of certain mining areas. They continue to thrive and expand despite the declining profitability of mining and the discontinuation of mines, e.g. Johannesburg and Kimberly in South Africa, Accra in Ghana, etc.

Most of these urbanisations have persisted, forming big urban agglomerations (Berger, 2006; Bryceson and MacKinnon, 2012; Fafchamps et al., 2017). Regions with high population densities, like Asia, Latin America and some parts of Africa, are a case in point. For example, the Xuzhou region in China is highly urbanised, characterised by post-mining remnants of the country's industrial boom (Wirth et al., 2018). In Latin America, Chile exhibits another example of the co-existence of post-mining and urbanisation. Most urbanisation in Chile owes much of its existence to diamond and copper mining (Phelps et al., 2015). Cities such as Copiapo and Antofagasta in Chile are characterised by post-mining features, with Copiapo alone scattering over 30 mine tailings dams (Carkovic et al., 2016). More locally, the Gauteng province, South Africa, is characterised as primarily urban land use (StatsSA, 2011; Harrison, 2007). Yet, much of this is on or adjacent to the mining activities of the Witwatersrand.

Therefore, investigating both these landscapes through an assemblage theory lens provides the much-needed opportunity to analyse the Gauteng landscape. Investigating its many characteristics and the relations between them, with particular emphasis placed on the post-mining and urban landscape characteristics.

3.4. SUMMARY OF THE CHAPTER

This chapter has introduced and expanded on the theoretical framework underpinning this research study, assemblage theory, including its characteristics and dimensions. Assemblage theory has been introduced as providing a wide range of concepts that offer unique and powerful ways of understanding, expressing and adapting notions of imminent change and complexity, and thus its applications for understanding landscapes. The chapter has also introduced the concept of the ‘landscape’, noting that this study operationalises the landscapes as a unit of study albeit comprising many characteristics. Landscapes have been introduced as having many definitions and interpretations. The review of landscapes is followed by an outline of the genealogy of the two landscapes of interest, post-mining and urban landscapes. These two landscapes are discussed generally, followed by a contextual overview of post-mining and urban landscapes in Gauteng. Post-mining, mining and urban landscapes are complex, and more so when they co-exist. This co-occurrence presents new challenges and new dynamics manifest. This chapter also introduces, through the discussion of post-mining and urban landscapes in Gauteng, the co-existence of these two seemingly conflicting landscapes. By so doing, this chapter sets the stage for the next chapter, which discusses Geographic Information Systems (GIS) and their applications in similar landscape research, which is sometimes faced with the challenge of integrating contrasting landscape characteristics.

CHAPTER FOUR: OVERVIEW OF THEORY AND APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS

4.1. INTRODUCTION

This study aims to develop a Geographic Information Systems (GIS)-based framework for conceptualising, integrating, analysing, visualising and managing the historical and contemporary characteristics of Gauteng’s urban and post-mining landscapes. Thus, this chapter introduces GIS as a leading technology applied in many studies to integrate and visualise spatial characteristics. This chapter starts by interrogating the history of GIS, how real-world abstractions are represented and the critiques of representations of space in GIS. A discussion of the applications of spatial multicriteria decision-making and GIS-based spatial framework in integrating various data for the integrated visualisation, analysis and storage of spatial data follows this. This is followed by a discussion of practical examples of the applications of integrated spatial frameworks in general and studies related to urban and post-mining landscapes.

4.2. GEOGRAPHIC INFORMATION SYSTEMS

Before the advent of GIS in the 1970s, the manipulation, synthesis, and representation of geographic information were limited to manual mapmaking on paper, lacking interactivity (Luaces et al., 2004). The emergence of computer-based technologies, coupled with the growing demand for interactive manipulation and analysis of geographic data, necessitated the development of GIS (Luaces et al., 2004). While traditional cartography relied on paper maps as analogue databases (Marble 1990), GIS surpasses that role, offering extensive capabilities beyond paper map production (Luaces et al., 2004). GIS is a computer-based system with a well-defined management structure encompassing software, hardware, procedural mechanisms, processors, peripherals, and georeferenced spatial data. It enables the visualisation, analysis, manipulation, storage, and management of spatial data related to geographic phenomena (Burrough and McDonnell, 1998; Salap, 2008). These data are crucial in addressing complex human-related issues (Ahmed et al., 2021).

GIS consists of four sub-systems: data entry, data storage and retrieval, data manipulation and analysis, and visualisation and reporting (Marble, 1984). The data entry sub-system facilitates the translation of location attributes into geographic coordinates, maintaining intricate spatial relationships (Peuqet and Marble, 1990; Al-Shuhail, 2002). The data storage sub-system efficiently structures the database for data retrieval (Marble, 1984). The data manipulation sub-system transforms data into usable formats, enabling analysis or providing an interface for analysis (Marble, 1984). The data visualisation and reporting sub-system allows for the visual representation of different models, employing multi-dimensional and diverse approaches to data interpretation.

GIS is highly effective in creating maps that display the geographic locations of spatial features like rivers, parcels, or political boundaries. Moreover, it adds value by mapping multiple characteristics of spatial locations into thematic maps, displaying feature variations across space (Hillier, 2010). GIS encompasses various analytical tools, some assessing or quantifying relationships between spatial features, setting it apart from graphics software-generated illustrations produced individually (Hillier, 2010). GIS is the foundation for comprehensive interventions in an area, offering tools for ongoing planning, monitoring spatial evolution, evaluating the effectiveness of existing measures (Giannopoulou et al., 2014), and making predictions based on current and historical practices. In this regard, GIS proves helpful in analysing and managing natural or human-induced hazards, assessing changes in land characteristics (Al-Shuhail, 2002), supporting land restoration decision-making (Duzgan et al., 2011), predicting future land use based on historical data (Al-Shuhail 2002), monitoring ecosystems and the environment, and managing properties and assets.

Additionally, GIS provides a mechanism for making informed decisions regarding the remediation of environmental issues associated with mining and related activities (Duzgan et al., 2011). Consequently, GIS enables a more exploratory mapping process (Hillier, 2010). It has evolved from a specialised technology primarily used in the military to a versatile tool with applications across various disciplines. As a result, the functional requirements for GIS are extensive and exceed those of traditional information systems like Oracle and Microsoft Access (Luaces et al., 2004).

4.3. GIS REPRESENTATIONS OF REAL-WORLD ABSTRACTIONS

Spatial knowledge exists in our minds from dealing with space and spatial relationships. It represents one of the most basic facets of any human society (Peuqet and Marble, 1990). The only way of understanding it is through external content, such as the spatial behaviour of objects and using spatial language– using deliberate language to describe one’s physical surroundings. This deliberate description of the physical surroundings can, for instance, describe the location, size, shape, orientation of objects and places, as well as the distance, direction, and movement. For a long time, human societies have desired to communicate their accumulated spatial knowledge (Peuqet and Marble, 1990). As Tsai and Lo (2013) note, researchers and human societies have used different methods to externalise human spatial knowledge, most commonly through the use of maps (Peuqet and Marble, 1990), which reached their peak as a social investigation tool in the 1880s (Vaughan, 2018).

Spatial knowledge and the representation of geographical phenomena can take many forms. Cartography flourished in the 16th and 17th centuries and is defined as the art, science, and technology of making and using maps (Ricker et al., 2020). It has been at the forefront of representing spatial phenomena, reproducing spatial knowledge, and familiarising the world (Krupar, 2015). Maps are produced following a cartographic workflow and use various representation and visualisation techniques capable of persuasion, description, and projection, simplifying and communicating complex spatial phenomena (Desimini and Waldheim, 2016). Maps depict complex spatial characteristics such as landscapes and societies (Crampton and Krygier, 2005; Barton and Irrazaval, 2014; Desimini and Waldheim, 2016). In some cases, maps are used for strategic purposes such as navigation, planning and executing war, locating valuable resources, collecting taxes, declaiming territories, and creating and recognising territories and propaganda (Krupar, 2015). Maps make it easier for individuals to orient themselves geographically to natural features using a compass.

During the 16th and 17th centuries, initial maps were hand-drawn and were more figurative and pictorial to convey the landscape's shape and pattern. However, these maps are considered less precise, symbolic, or lovely pictures (Vannieuwenhuyze, 2019). Recently, accurate mapping techniques, such as GIS, have been used to create maps and conceive space as an assemblage of independent objects (Gold, 2005). GIS technologies use two fundamental conceptions of space (Brown et al., 2005): raster and vector data structures. Raster data maps represent space as a continuously varying distribution of geographic variables using pixels with discrete attribute values and sub-dividing them regularly (Yuan, 1996; Brown et al., 2005). Maps using vector data represent spatial features as discrete entities, which have a location, a spatial extension and attributes, such as lines, boundaries, discrete attribute fill (such as polygon classes) or continuous fill (such as smooth topography) (Krupar, 2015). Although some phenomena may be represented using a raster or vector model, some geographic phenomena have field and object characteristics in some cases and might require a combination of these views (Brown et al., 2005). As such, real-world objects in GIS are represented in several ways to represent the dynamic character of landscapes. For example, by taking advantage of the location, size, colour value, texture, colour intensity, orientation, and shape (Desimini and Waldheim, 2016; Mackenzie et al., 2017). Moreover, GIS makes it easier to layer data on different themes, periods, and geographic scales (Hillier, 2010).

Additionally, the representation of spatial features is a multi-dimensional issue (Kemp, 1993). Most GIS packages are based on two-dimensional (2D) geometric representations (Li, 1994), where the location of a spatial feature is based on two independent coordinates (Gold, 2005). These maps represent the spatial area as a flat surface with a set of adjacent polygons or a network of lines (Gold, 2005). However, the representation of the earth on a flat surface has several drawbacks, owing to the earth's spherical shape. The representation of the Earth on a 2D, flat surface is distorted in representing the Earth's true area, direction, distance and shape (Li, 1994; Gold, 2005).

Nevertheless, these inaccuracies can be alleviated through projection, a mathematical algorithm that defines how to take a three-dimensional representation feature and represent it on a two-dimensional surface (Janssen, 2009). Although several projection systems exist, their applications depend on the spatial features the user wants to emphasise, the applications of the map or the region being represented. On the other hand, spatial features can also be mapped using three-dimensional (3D) geometric representations, initially used in Computer-Aided Design (CAD) and Computer Graphics systems (Li, 1994). Using 3D, spatial objects are simplified and represented as points, lines, and polygons in vector data structures or by pixels in raster data structures. In contrast, terrain models are represented by grids and Triangulated Irregular Networks (TIN) (Li, 1994; Merlo, 2016). The main advantage of 3D representations of the Earth is that they require less human information processing as there is no need to construct the third dimension to have an accurate mental model of the Earth's surface (Janssen, 2009). However, Kemp (1993) argues that no matter how well a spatial data model represents reality, it has limitations. This can be seen in how, despite the applications of GIS in the representation of spatial phenomena, it has been critiqued for many reasons.

First, for a long time, maps were believed to be objective depictions of present-day geographical conditions and accurately represent the earth's surface (Krupar, 2015; Vaughan, 2018; Alderman et al., 2021). However, maps are social constructions (Desimini and Waldheim, 2016). Their precision is based on their scale, underlying data, editorial choices, and representational method (Desimini and Waldheim, 2016), such as the class intervals chosen in a choropleth map. Kurgan (2013) notes that another distortion and source of error in maps may stem from data from many sources and times but represent the space as if the underlying data were uniform. In addition, maps may also be influenced by human factors. For instance, Crampton and Krygier (2005) argue that mapmaking software is now available to anyone with a home computer and an internet connection. The broader availability of mapmaking software has been seen as an assumption of power and resistance to hegemony, providing the platform to rework the meaning and applications of geographical knowledge (Del Casino and Hanna, 2006; Vaughan, 2018; Ricker et al., 2020). However, Kim (2015) argues that this demands greater reflexivity from new cartographers about their power positions in society and their influence on the critical map project.

Similarly, Hill et al. (2016) call for more examination of data to uncover hidden details within them. Thus, there has been an increase in the push for transparency in governmental data, particularly spatial data. Ricker et al. (2020) argue that access to open data would offer opportunities to analyse data used by decision-makers, produce maps that display data in different ways, and communicate with decision-makers in a visual language they already understand. More so, open access to data for mapping would allow for identifying gaps by a critical map reader (Ricker et al., 2020). For example, recent years have seen the establishment of the Google Earth Engine, which has been widely used since the early 2000s, allowing citizens to be more spatially aware of their physical and social surroundings through the digital representation of the earth (Liang et al., 2018).

Second, scholars such as Kwan (2002) and Lesh (2016) argue that GIS is limited in its applications for critical human geographic research, such as feminist research approaches, as it does not consider power imbalances between research and subject. While maps can be helpful in advocacy (Peuqet and Marble, 1990), feminist scholars argue that GIS and cartography are authoritative and unquestionable when the map-making process is filled with decision-making and uncertainty (Ricker et al., 2020). Similarly, Kelso (1999) and Elwood (2002) also review GIS's use of vision and visualisation as the primary mode of knowledge production and dissemination. They argue that maps, despite other factors informing them, are primarily technocratic and benefit mostly those with access to technology. In GIS, there is also a tendency to map features using sharp and hard boundaries. Points, lines, and polygons are given coordinates and time-stamps to show start and end points (Mackenzie et al., 2017), oversimplifying the earth's surface. This is deeply problematic when paired with the perception of maps as accurate and as creating rather than merely representing place and space, as this gives maps a form of power, often enforcing existing power relations (Sui, 1994; Kelso, 1999; Pickle, 1999). Similarly, Harley (1997: 237) argues that the steps included in the map-making process include "selection, omission, simplification, classification and the creation of hierarchies, and therefore the 'symbolisation' are all inherently rhetorical", and this is a form of power.

Third, other studies (e.g. Sui, 1994; Pickle, 1999; Kwan, 2002) critique GIS based on its representation of space. These studies argue that GIS is inadequate in its representations of space as it uses reductionist ontologies of spatialism. Sui (1994) and Kwan (2002) argue that this is because GIS does not recognise the natural and anthropogenic processes that shape landscapes, therefore making it challenging to model urban geographies on a simple digital platform as a raster or vector (Sui, 1994; Kwan, 2002). Similarly, the flat nature of maps does not accurately represent that all existing objects are three-dimensional (Laurini and Milleret-Raffort, 1992; Merlo, 2016). Moreover, Desimini and Waldheim (2016) argue that maps are also inherently static and out-of-date. Peuquet (2002) suggests that the focus of data models in GIS has been on spatial, at the expense of temporal dimensions, proposing extensions to existing spatial data models to provide richer representations of time and space (Brown et al., 2005; Mackenzie et al., 2017). This is to say that when spatial features of the real world are translated to a projected image, there is a time-lapse, and the Earth's surface has already experienced a level of change (Desimini and Waldheim, 2016). In the rare inclusion of temporal referencing or time-based attributes, some data models have not included explicit representations of the processes (i.e., sequences of operations) by which spatial features change and move, focusing instead on representing the changing structure of the phenomena (Brown et al. 2005). GIS is essential for understanding a territory's past spatial conditions and potential (Desimini and Waldheim, 2016). Thus, efforts have been made to simultaneously represent space and time (Aigner et al., 2011). Time on maps is represented through experimentation with line weight, tonal change, and applying different levels of detail and different conditions - from past to future (Desimini and Waldheim, 2016). Time can also be represented using overlays or a graphical hierarchy, resulting in a composite image where multiple periods can be visualised simultaneously (Desimini and Waldheim, 2016). Yuan (1996) also notes that other techniques for visualising space and time recognise that time can be invoked in the layers, and temporal constructs can be incorporated into GIS data models.

Fourth, the representation of spatial features in cartography and GIS generally follows a mostly Eurocentric understanding of the world. Mapping has always been a crucial tool for European imperialism, its popularity peaking in the 19th century during speculations regarding the expansion of their respective empires in Africa — despite the existence of local mapping practices — (Oslender, 2021), with the perspective and worldview of space continuing to be that of colonial powers in the present (Bellone et al., 2020). All the while, indigenous concepts of space and time are inadequately represented and explored in the mapping (Mackenzie et al., 2017). Mackenzie et al. (2017) suggest that western mapping employs more precise boundaries, such as the lake shore. However, Lefebvre argues that space is not concrete, lacks territorial contiguity, and is socially constructed (Larsen and Beech, 2014), as evidenced by indigenous mapping practices, where areas are often literally ambulatory and relative. For example, the location of a herd or following natural features. Röing et al. (2021) suggest that spatial realities may be represented using 'hard-GIS' (valuing expert knowledge and employing more general landscape preferences) and 'soft-GIS' (which are more participatory[18] and employ user-dependent methods). However, many elements of ambiguity and dynamism in spatial representation are important to include in maps for accurate reflection of local realities. For instance, using both hard and soft-GIS methods to account for both an expert view complemented with a subjective view (Röing et al., 2021). However, as Ricker et al. (2020) note, honouring all viewpoints in a single map may not be entirely possible. D'Ignazio and Bhargava (2020) and other scholars using feminist approaches suggest connecting data to their contexts to understand better their limitations, ethical obligations, and how power and privilege may obscure truths. Thus, several researchers have suggested moving towards more

[18] Participatory Geographic Information Systems (PGIS) refers to the public participation practice entailing the use of community mapping practices to generate spatial information (Brown et al. 2018). PGIS has been particularly useful for enabling communities to map their surroundings, landscapes and resources. Some studies, such as those by, Fagerholm and Kayhko (2009), Hessel et al. (2009), Brown and Weber, 2012; Brown et al. (2012, 2018), and Fagerholm et al. (2019), employ PGIS mapping methods to assess landscape services and utilize this data for various GIS analyses. However, only a limited number of studies, including those by Harmsworth (1999), Fagerholm and Kayhko (2009), Hessel et al. (2009), Brown et al. (2012, 2015, 2018), and Fagerholm et al. (2012), explore the practical integration of both tangible and intangible aspects of a geographic area.

critical approaches to GIS (Oslender, 2021), stemming from the same critical philosophy as critical cartography[19].

4.3.1. Critical cartography

As narrowly understood among academic geographers and cartographers, *critical cartography* is a relatively recent academic phenomenon. According to Rogers et al. (2015), critical cartography does two things simultaneously: critiques cartography and seeks to practice critical map-making. Criticism has been part of mapmaking from its earliest days, driven mainly by the purposes for which they are used (Rogers et al., 2015). Criticism is inherent in mapmaking to settle conflicting reality claims (Rogers et al., 2015; Wood et al., 2020). Thus, critical cartographic studies have come to be understood as paying close attention to the work behind maps and mapping (Wood, 2010), emphasising human labour and social practices behind map-making as social actors and groups engage cartographic objects, practices, and spaces. Critical cartography challenges academic cartography by considering spatial information through a lens cognisant of political influences and power on spatial knowledge production (Crampton and Krygier, 2005). Critical cartography also considers mapping a method for redoing a place whose effects can be recognised and challenged (Rogers et al., 2015). It seeks to use maps as an active intervention for furthering the spatial justice agenda (Antunes et al., 2020). Critical cartography confronts the associations between cartography and the precision and definitude of the map. Critical cartography goes beyond the mere visualisation of space by counter-mapping space and questioning the underlying intentions of the map. According to Cattoor (2019), counter-mapping is called critical re-mapping. This expands the spatial imagination and augments the capacity of designers, stakeholders and social groups to engage constructively with the environment. This process encompasses decolonising maps of the privileged worldviews projected in and through maps and transforming the authority to write the earth (Antunes et al., 2020; Alderman et al., 2021). Critical cartography calls for a specific form of reflexivity or relentless recognition of the manufacture of maps (Rogers et al., 2015).

Thus, a critical GIS would overlap but not necessarily coincide with critical cartography[20]. While stemming from the same critical philosophy described above, critical GIS refers to the social implications of GIS software and hardware in mapping and representing space (Crampton and Krygier, 2005). A critical GIS would then reveal the space between representation and intervention and bring

[19] A philosophy combining mapping technologies and cartographic tools and increasingly allows for wider creative access as well as a critical perspective on the politics of space and place (Crampton and Krygier, 2005).

[20] Critical cartography is broader referring to maps, mapping as well as the mapmaking itself (Crampton and Krygier, 2005).

forth methods for addressing and mediating the effects of mapping while remaining attentive to the more technical decisions of map production (Wilson, 2015). Similarly, Carrion et al. (2009) argue that the rise of digital cartography has called for the increase of data archival practices using many structures, such as geographical databases. This move is instrumental not only for having data archival structures and for developing representation rules but also for integrating a variety of data that can be used to critique and compare how space in a particular area is represented. Nevertheless, despite the critiques of GIS in its representation of space, it is still commonly used to represent space and the resultant landscapes.

4.4. GIS AND MULTICRITERIA-DECISION MAKING

Multicriteria Decision Analysis (MCDA), also known as Multicriteria Decision Making (MCDM) and used interchangeably, is a widely used approach that evaluates and compares alternatives based on multiple criteria (Roy, 1996; Belton and Stewart, 2002). MCDA recognises that decision-making often involves multiple objectives or factors that a single criterion cannot adequately capture. Therefore, in these situations, the multicriteria analysis provides a structured decision-making method to synthesise and combine different criteria with supporting, evaluating and selecting alternatives (Roy, 1996) and their interrelationships. By doing so, MCDA helps to understand the trade-offs involved in decision-making and supports the selection of alternatives that best meet the objectives (Roy, 1996).

MCDA is used in land use planning, particularly in suitability studies, based on the premise that land use suitability analysis is an appropriate means of quantifying land features, constraints and opportunities. Therefore, land use suitability analysis studies are mainly employed to identify the most suitable locations for present and future land use (Collins et al., 2001; Malczewski, 2004).

MCDA[21] and an analytic hierarchy process (AHP)[22] are commonly applied in land use suitability assessments (Banai, 2005). An analytic hierarchy process (AHP) is a mathematical method developed by Saaty (1980 in Saaty, 2008). Using multicriteria decision analysis effectively quantifies the importance of all considerations in a model or process (Table 2). It is a decision-making technique in a

[21] Roy (1996) defines MCDA as a tool, allowing the evaluation of different alternatives or scenarios according to many criteria (often conflicting), in order to guide the decision maker towards a sensible choice. MCDA thus assists decision makers in the organisation and synthesis of large amounts of data (Belton and Steward, 2002:2). Spatial multi-criteria decision-making refers to the application of MCDA in a spatial context, where the elements involved in the decision making process have specific spatial dimensions (Chakhar and Mousseau, 2007).

[22] A particular strength of AHP pertains to its ability to handle quantitative attributes as well as qualitative ones.Thus AHP has wide-ranging applications in a multitude of decision situations, such as business, government and education (Banai, 2005). In this research study, AHP is employed to determine the relative importance of post-mining and urban landscape characteristics.

structured format based on the hierarchical framework using pairwise comparisons. This is done mathematically to derive weights for every decision-making criterion from the pairwise comparisons of importance between two criteria and is repeated until all the criteria are compared (Banai, 2005; Malczewski, 2004).

Table 2: Scale for pairwise comparison. Source: Saaty (1980 in Saaty, 2008).

DEFINITION	**INTENSITY OF IMPORTANCE**
Extremely more important	9
Very strongly to extremely important	8
Very strongly more important	7
Strongly to very strongly more important	6
Strongly more important	5
Moderately to strongly more important	4
Moderately more important	3
Equally to moderately more important	2
Equally important	1

Applying these two methods is crucial for examining all factors affecting the feasibility of a plan, as it enables a comprehensive assessment of multiple criteria (Wang, 2013). However, MCDA is also a widely used framework in GIS studies, where spatial data plays a crucial role. MCDA offers a systematic and transparent framework for evaluating alternatives based on various spatial criteria. According to Malczewski (2006) survey of the literature relating to GIS-based multi-criterion decision analysis, GIS-MCDA approaches are popular in addressing land suitability problems. Most of these land suitability assessments focus on identifying the most suitable arable land for agricultural purposes. However, other land uses and specific sites in urban areas have also been the subject of several studies.

MCDA techniques in GIS offer numerous benefits in spatial decision-making processes. It allows decision-makers to consider and evaluate multiple criteria, considering their interrelationships explicitly. MCDA facilitates a systematic approach to decision-making, providing a structured framework for evaluating alternatives and understanding the trade-offs involved. It also allows for incorporating expert knowledge and preferences into the decision-making process, enhancing the reliability and transparency of the decisions made. However, some authors (Malczewski, 2004; Cilliers, 2010; Ulla and Mansourian, 2015) have noted several problems related to applying MCDA techniques in GIS. These problems range from inaccuracies in the data, justification of the applied methods, standardisation of criteria, etc.

Nevertheless, recent years have seen the increasing adoption of multicriteria analysis, with AHP also being combined with GIS technology to develop what has been termed the Spatial AHP (SAHP) method for spatial multi-criterion analysis. A particular strength of the method is its ability to deal with quantitative and qualitative attributes. AHP has several advantages over standard techniques as it relies more on expert opinions than the completeness of data; it allows planners and other stakeholders to provide their views in making land use suitability measurements. Additionally, AHP can set the criteria of land-use planning in a structured way based on available data and standardise the criteria with its simple mathematical operations. When data cannot be quantified objectively, AHP allows subjective judgments consistently. GIS-based AHP can overlay all the standardised criteria that help to make rankings on a locational basis (Ullah and Mansourian, 2015). Thus, AHP has been used to guide multicriteria decision analysis in various decisions, such as business, government and education.

Several studies have been relevant to this research, all looking at an urban landscape or development aspect. For example, Aly et al. (2005) developed a GIS-based model that incorporates suitability factors such as land use or cover, types of soil, karst feature distributions, fracture densities, slopes, distances to significant faults, streams and road network, and city boundaries. On the other hand, Dai et al. (2008) evaluated the suitability of industrial land use in the planning of industrial cities based on ecological suitability evaluations. Further studies by Soltanmohammadi et al. (2009), Bielecka and Krol-Korczak (2010), Król-Korczak and Brzychczy (2019), Sitorus et al. (2019) and Arratia-Solar et al. (2022) suggest that MCDA has also been widely used in the various stages of mining, including mine closure. However, there are limited studies on their applications for closure. At the same time, Roy (1996) argues that in situations with contrasting characteristics, MCDA is required to combine all characteristics. In a spatial context, spatial multi-criteria decision-making is applied, and the elements involved in the decision-making process have specific spatial dimensions (Chakhar and Mousseau, 2007).

Multicriteria analysis typically involves several key steps, represented graphically in Figure 8. The decision-making process is divided into three parts, namely: input, MCDA, and output (Elmahmoudi et al., 2018). The first part entails problem formulation, which includes clearly defining the decision problem and identifying the objectives and criteria, where one criterion is regarded as an affecting factor considered in the decision-making process. According to Wong (2006), the criteria should be identified based on existing literature from planning theories and expert interviews from planning practice. Then, this is followed by the criteria selection, where relevant criteria for evaluating the alternatives are identified. Data collection involves gathering the necessary data for each criterion, followed by criteria weighting, which assigns relative importance or significance to each criterion. Theories should guide the quantitative or qualitative measurements or weighting of the criteria. The steps taken in weighting criteria are discussed below (Wong, 2006). The next part entails data analysis and modelling to generate decision outcomes. Finally, decision synthesis combines the analysis results to provide a comprehensive evaluation, selection of alternatives and recommendations (Belton and Stewart, 2002).

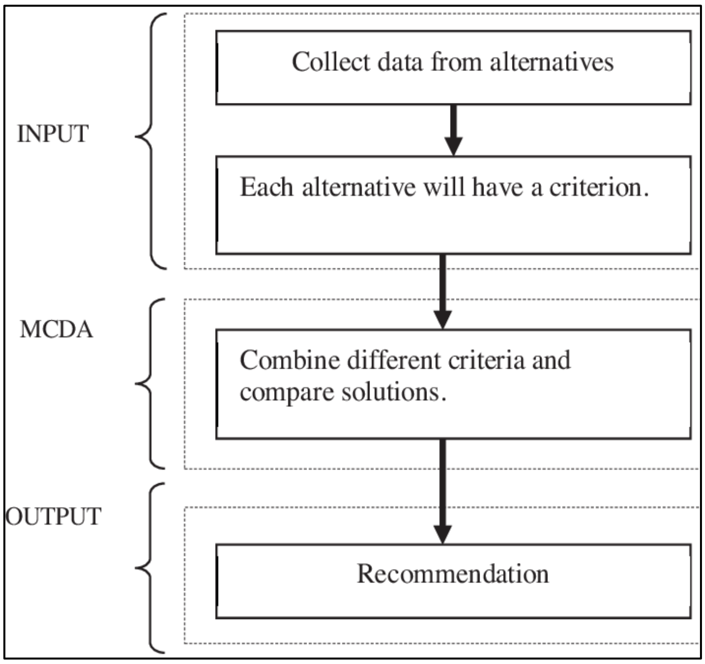


Figure 8: Multicriteria decision-making process. Source: Elmahmoudi et al. (2018).

Multicriteria decision-making in GIS provides a powerful framework for evaluating alternatives, spatial data, and interrelationship analysis, enabling decision-makers to address complex spatial problems, optimise resource allocation, and support sustainable development. MCDA in GIS is an essential tool for tackling the challenges of today's spatial decision-making processes. Several methodologies and techniques are employed in MCDA within GIS (Malczewski 2006, Wang 2013). Some of the commonly used ones, although not an exhaustive list, include Geographical Weighted Regression (GWR), Analytic Hierarchy Process (AHP) (Saaty, 1980), Fuzzy Logic, Weighted Overlay – one of the most popular MCDA methodologies - along with predictive methodologies such as Random forest classification (Belton and Stewart, 2002). The latter three are applied in this research and are discussed below.

4.4.1. Fuzzy Overlay

Fuzzy overlay is a multicriteria analysis technique incorporating fuzzy logic principles into GIS operations (Malczewski, 1999). Fuzzy overlay is based on fuzzy logic, a mathematical framework based on fuzzy set theory. Zadeh (1965) laid the foundations for fuzzy set theory, and since then, it has become an area of growing research interest, especially with the development of GIS. This theory provides a mathematical framework for investigating conceptual phenomena that are imprecise. Fuzzy overlay uses a generalisation approach, using weighted membership with more than two elements rather than a binary choice of two elements. This membership weighting allows a continuum of possible choices that can be used to describe imprecise terms (Zimmermann, 2010). Thus, fuzzy overlay enables the representation and manipulation of imprecise or uncertain information by employing fuzzy sets and membership functions. Fuzzy overlay combines multiple spatial data layers by assigning fuzzy membership values to each layer based on their relevance to the decision-making criteria. Fuzzy membership values represent the degree of suitability or membership of each spatial unit (e.g., grid cell, polygon) in the layers. A total fuzzy overlay output is generated by overlaying and aggregating fuzzy membership values, representing the overall suitability or decision surface (Malczewski, 1999).

Fuzzy overlay is helpful as a multicriteria decision tool as it considers that some spatial features, such as buildings and electric transmission lines, have hard physical boundaries. However, not all spatial features have such hard boundaries. Most spatial phenomena have attributes and extents that vary according to location and definition. According to O'Sullivan and Unwin (2010), these spatial features would be termed as having fuzzy boundaries, where fuzziness is a way of representing a gradational property of spatial phenomena, such as soil, which varies across its boundaries and transitioning from one type or category to another over a distance. Such spatial features seldom have precise definitions and comprise a combination of threshold values. As such, working with these data may be difficult as they do not fit binary logic. However, fuzzy overlay techniques are advantageous because the analysis uses continuous datasets that are difficult to divide into binary suitability classes, such as continuous data.

Fuzzy overlay analysis is conducted in two phases. First, the criterion used in the analysis must be converted to fuzzy membership values using the fuzzy membership functions (Table 3, Figure 8 and Figure 9), a host of which can be found in Esri's membership tool (Rosenbery, 2019). Fuzzy membership functions examine the range of values in the fuzzy dataset and assign a fuzzy value ranging from zero to one (Rosenbery, 2019). According to Bielecka and Krol-Korczak (2010), fuzzy membership functions are also useful for converting linguistic descriptions from experts into values usable for computers. Common membership functions can assign high to low membership or membership centred on an ideal value (Rosenbery, 2019). These functions, therefore, operate by favouring criteria in a dataset along a continuous scale instead of creating discrete binary categories of suitability (Mitchell, 2012), preventing the creation of unnecessary or inaccurate binary relationships in the analysed data. The membership value scale is from zero to one, where zero is non-membership, and one has a full membership status, while the infinite values in-between have likely or partial membership. Most data points fall between zero (0) and one (1).

Table 3: ESRI fuzzy membership function descriptions. Source: Raines et al. (2010).

Membership Function	Description	Definition
Linear	A linear increasing or decreasing membership between two inputs. A linearized sigmoid shape.	$\mu(x) = 0 \; if \; x < min, \mu(x) = 1 \; if \; x > max,$ $otherwise \; \mu(x) = \frac{(x - min)}{(max - min)}$ where min and max are user inputs
Large	Sigmoid shape where large inputs have large membership	$\mu(x) = \frac{1}{1+\frac{x^{-f_1}}{f_2}}$ *where user inputs f_1 is the spread and f_2 is the midpoint*
Small	Sigmoid shape where small inputs have large membership	$\mu(x) = \frac{1}{1+\frac{x^{f_1}}{f_2}}$ *where user inputs f_1 is the spread and f_2 is the midpoint*
MS Large	Sigmoid shape defined by the mean and standard deviation where large inputs have large memberships.	$\mu(x) = 1 - \frac{bs}{x - am + bs} \; if \; x > am \; otherwise \; \mu(x) = 0$ where m = mean, s = standard deviation and *b* and *a* are multipliers provided by the user.
MS Small	Sigmoid shape defined by the mean and standard deviation, where small inputs have large memberships.	$\mu(x) = \frac{bs}{x - am + bs} \; if \; x > am \; otherwise \; \mu(x) = 1$ where m = mean, s = standard deviation, and *b* and *a* are multipliers provided by the user.
Near	A curved peak of membership over an intermediate value.	$\mu(x) = \frac{1}{1+f_1*(x-f_2)^2}$ *where user inputs f_1 is the spread and f_2 is the midpoint*
Gaussian	A Gaussian peak of membership over an intermediate value.	$\mu(x) = e^{-f_1} * (x - f_2)^2$ *where user inputs f_1 is the spread and f_2 is the midpoint*

As demonstrated in Figure 8, a mathematical or logical function determines the relationship between the observed values and the membership values created, controlling the dataset distribution between membership and non-membership. Assigning a fuzzy membership value to the observed data can manifest through various relationships (Table 3). Figure 9 presents plots of how the above functions work. For example, a linear relationship (E, in Figure 9) occurs when full membership is assigned to large or small observed values, and the rate of change to non-membership is consistent. The smallest or largest observed values in the linear function can be altered to create thresholds called minimums and maximums. These thresholds are helpful for completely excluding large or small observed values.

On the other hand, *Small* or *Large* functions can be used to create non-linear relationships between the datasets. The Small function (B) gives membership preference to small observed values, and the *Large* function (A) does the opposite. A rate of change can be manipulated to alter the nature of the function's spread. Additionally, a midpoint can be stipulated in the observed data where the fuzzy membership value will equal 0.5 (the midpoint between membership and non-membership). Although less commonly used, other relationships are possible with fuzzy membership functions, such as the Gaussian (C) and the Near functions (D). The Gaussian membership function assigns full membership based on the mean value and standard deviation from it. In contrast, the near fuzzy function relies more on mathematical relationships, commonly chosen over expert opinions. It is therefore not reported on, as they were not applicable in this study using literature for guidance.

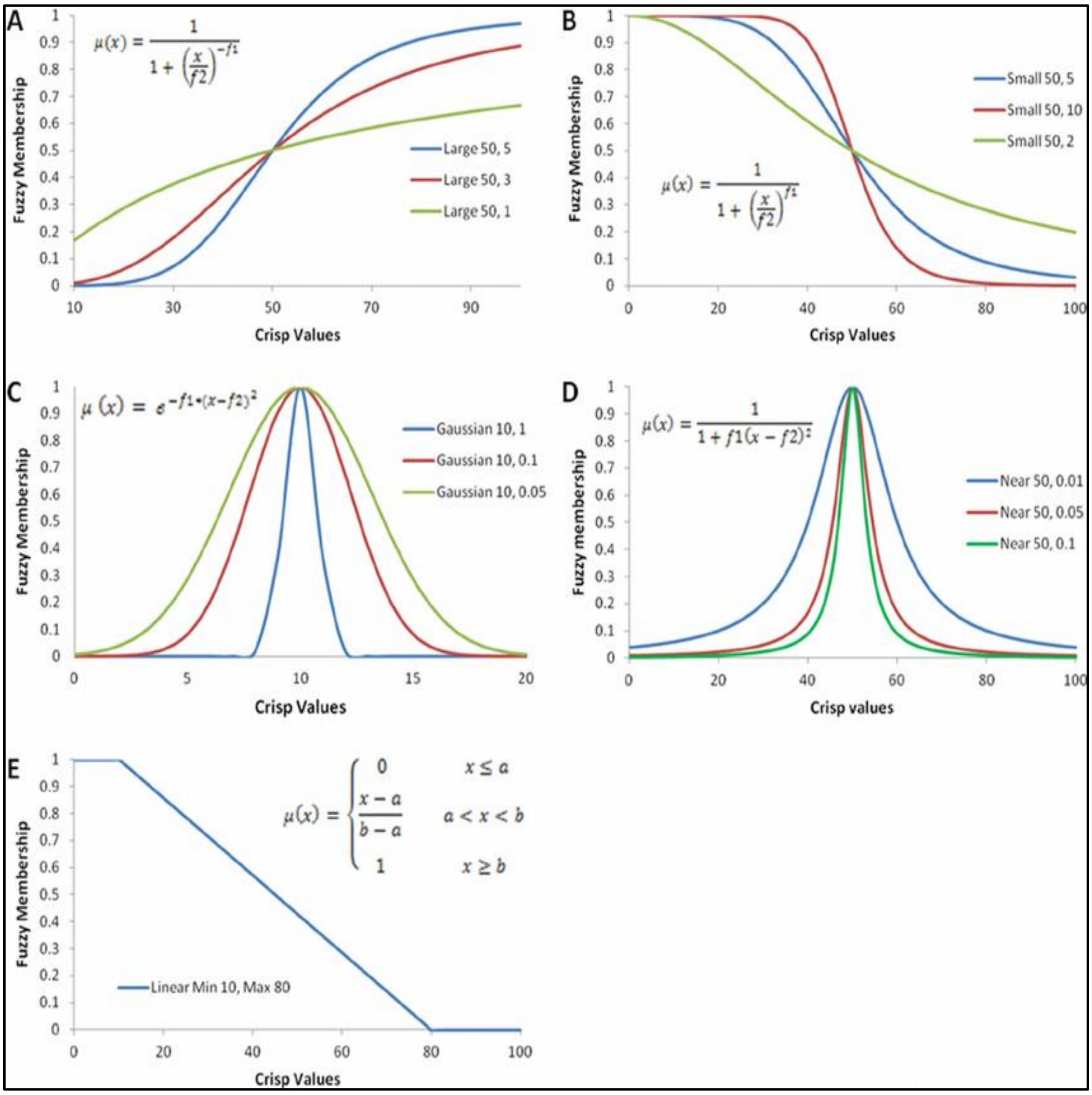


Figure 9: ESRI fuzzy membership function plots. Source: ESRI (2016a). A=Large function, B= Small function, C=Gaussian, D= Near function and E=Linear function. The different coloured lines moving

away from the graph indicate a decrease in membership or spread. The legends next to each graph indicate the input values, noting that a decrease in the input value affects the membership.

Phase two of the fuzzy overlay process entails overlaying the individual criteria layers (with fuzzy membership applied) using a fuzzy overlay operator (Rosenbery, 2019). The function and the order of fuzzy overlay operations (Table 4) used is one of the most influential components of the analysis, as it drastically affects the outcome. The method of operations determines the degree to which each membership layer contributes to the result, often referred to as the weight of its contribution (Mitchell et al., 2012). The *AND* operator returns the minimum value of the factors at the cell's location. The *OR* operator does the opposite and returns the maximum value of the factors at the cell's location. Other overlay operators available depend on mathematical operations, including product and sum, but are not particularly relevant to this analysis. The *PRODUCT* operator multiplies the values of each factor at the cell's location. However, it is not applicable in situations where it would return extremely small values. The sum operator adds the values of each factor at the cell's location and overemphasises values.

Table 4: Fuzzy overlay approach and methods. Source: Adapted from ESRI (2010, 2016).

MEMBERSHIP APPROACH	**METHOD**
Fuzzy And	Returns the minimum value of the sets to which the cell location belongs. This technique identifies the least common denominator for the input criteria's overall membership.
Fuzzy Or	This approach returns the maximum value of the sets to which the cell location belongs. This technique identifies the highest membership values for individual input criteria.
Fuzzy Product	This approach will multiply each of the fuzzy values for each cell for all input criteria. The resulting product will be less than any of the inputs, and the value can be very small when a member of many sets is input. It is difficult to correlate the input criteria's overall product to the values' relative relationship. This option is not used often.
Fuzzy Sum	This approach adds the fuzzy values of each set to the cell location to which it belongs, resulting in an increasing linear combination function based on the number of criteria entered into the analysis. Adding all the membership values in a fuzzy *SUM* analysis does not mean the location is more suitable than others. The fuzzy *SUM* option is not commonly used.

Fuzzy Gamma	This approach uses an algebraic product of fuzzy *PRODUCT* and *SUM*, both raised to gamma's power. If the specified gamma is 1, the output is the same as fuzzy *SUM*; if gamma is 0, the output is the same as fuzzy *PRODUCT*. Values in between allow the combination of evidence between these two extremes, possibly different from fuzzy *OR* or fuzzy *AND*. Fuzzy *GAMMA* compromises fuzzy SUM's increasing effect and fuzzy PRODUCT's decreasing effect.

Overlay analysis, which originated from Ian McHarg's overlay maps theory in GIS, is the most widely used function for character-related research. The landscape types or units are generated from the overlay of various landscape character variables (Simensen et al. 2018). Most of the data in this analysis are continuous datasets without mutually exclusive groupings. Fuzzy overlay as a methodology is, therefore, integral to this analysis because it is particularly well suited for data that is continuous, difficult to define, or derived from expert opinion. Additionally, a fuzzy methodology is suitable for this research because the fuzzy approach was successfully used in studies such as Gopal et al. (2016) to map urban landscapes. Gopal et al. (2016) argue that a fuzzy approach is useful for mapping urban characteristics as these seldom have precise definitions. Instead, they may comprise a combination of threshold values. A fuzzy approach allows for combining all these threshold values and provides greater flexibility to characterise the many facets of the urban landscape.

Owen et al. (2006) used fuzzy clustering to derive eight urban classes in an urban landscape in the West Midlands (UK) (Van Eetvelde and Antrop 2009). A fuzzy approach has also been used to support post-mining region restoration in Bielecka and Krol-Korczak (2010). This study suggests that while post-mining restoration can be algorithmic, many characteristics of a post-mining landscape do not follow a two-valued logic system. On the other hand, studies such as Arratia-Solar et al. (2022) demonstrate the applications of MCDM in assessing potential alternatives to post-mining landscapes by proposing a conceptual framework which combines spatial and socio-technical data to support decision-making. Additionally, other studies (Bielecka and Król-Korczak 2010, Król-Korczak and Brzychczy 2019) demonstrate the applications of fuzzy overlay in mining reclamation processes.

Thus, a fuzzy overlay approach is well suited for this research as it provides flexibility to determine favourability in the analysis for handling continuous datasets on post-mining and urban landscapes. Additionally, fuzzy overlay helps demonstrate this research's novelty in enabling the representation and manipulation of imprecise or uncertain information, in this case, the post-mining and urban characteristics of the Gauteng landscape.

4.4.2. Weighted Overlay

A weighted overlay is a widely used multicriteria analysis technique that involves assigning weights to criteria and combining them to generate an overall suitability or decision surface (Malczewski, 2006). This is done by calculating a composite score for each cell or spatial unit in the study area by multiplying the value of each criterion by its respective weight and summing the results. The resulting composite scores represent each cell's relative importance or suitability based on the criteria (Malczewski, 2006). As such, weighted overlay is one of the most commonly used functions when solving overlay functions with multiple criteria (ArcGIS Weighted Overlay function, 2020) and is especially applied in land suitability studies (Lodwick et al., 1990; Baidya et al., 2014).

A critical component in weighted overlay analysis is the determination of layer weights before the overlay process (Carver, 1991). The combination of multiple datasets is complicated not only by the selection of the spatial data but also by how the criteria are weighted in the overlay process, thus using a weighted overlay approach (O'Sullivan and Unwin, 2010; Rosenbery, 2019). Weightings reflect the relative importance or significance assigned to each criterion in the analysis and represent the decision-maker's preferences and priorities. Therefore, the layer weights represent the relative perceived importance of the overlay components (Carver, 1991). The primary purpose of weighting is to leverage the relative influence of individual criteria against each other. This becomes especially critical when considering a hierarchy of importance concerning criteria (Rosenbery, 2019). Thus, weighted overlay analysis provides a better approach to criteria that include many conflicting attributes or objectives (Carver, 1991; Rosenbery, 2019). However, the defined relative importance of criteria should be founded in sound data-driven reasoning instead of ad hoc estimation (Malczewski, 2000). To this end, the importance of the criteria is determined through a process of data interrogation and evaluation, which also employs a process to select a hierarchy of importance within the criteria considered (Rosenbery, 2019). Different weighting methods can be used in the weighted overlay depending on the decision context and available information. Standard weighting methods include equal weighting, rank ordering, AHP, and data-driven methods. Each weighting method has its assumptions, advantages, and limitations, and the choice of method requires careful consideration based on the specific context (Malczewski, 2006).

Although GIS and MCDA are independent systems, Malczewski (2010) notes that they have been combined over the years. As such, weighted overlay in GIS can be accomplished in multiple ways and entails several steps. First, as weighted overlay entails the overlay of multiple criteria, these criteria are seldom present in the same scale or range of classification. First, they must clearly define the decision problem and identify the criteria relevant to the analysis. This step involves engaging stakeholders and experts to determine the criteria that best represent the decision context. Next, decision-makers must collect or acquire the necessary spatial and attribute data corresponding to the selected criteria. Hence, once the data is gathered, decision-makers must assign weights to each criterion to reflect their relative importance to proceed with the overlay. The weighting process can be subjective, where decision-makers assign weights based on their expertise and judgment, or it can be derived from quantitative techniques such as the AHP that involves pairwise criteria comparisons to determine their relative weights (Saaty, 1980). After assigning weights, decision-makers apply the weighted overlay operation in GIS to generate the composite scores or suitability surface.

The criterion layers must be reclassified to a standard scale using a reclassification tool (Samhita, 2020). This involves multiplying the value of each criterion by its respective weight and summing the results for each spatial unit. The resulting composite scores can be visualised as a continuous surface, enabling decision-makers to identify areas with higher suitability or preference for the desired purpose (Malczewski, 2006). For example, the scale ranges from 1 - 5, wherein a value of 4 is preferred twice to 2 (ArcGIS Weighted Overlay function, 2020). Once reclassified, the criterion layers are then multiplied by weight to assign relative importance to each:

$$S = \sum_{i=1}^{n} \quad w_i * v_i$$

Wherein:

S= Land user suitability

i= layer number

n= number of layers

w_i= weight of layer i

v_i= value of layer i

(*= symbol for product)

Figure 10 graphically explains how the *Weighted Overlay* function works. All criterion layers have individual pixel values. The whole layer has an overall weight. The score for a pixel x across multiple layers will be the sum of the value of x on each layer multiplied by the weight of each layer (Weighted Overlay, 2020).

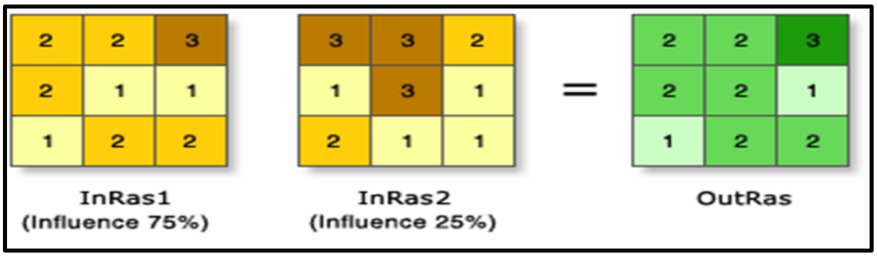


Figure 10: Representation of background workings of the weighted overlay function. Source: ArcGIS Weighted Overlay function (2020).

Thus, weighted overlay offers several advantages in multicriteria decision-making in GIS. First, it provides a transparent and quantitative approach to decision-making by explicitly considering the relative importance of criteria. This allows decision-makers to communicate and justify their decisions based on objective measures. Second, weighted overlay enables the incorporation of expert knowledge and preferences into the decision-making process, capturing the nuanced understanding of the decision context. Third, it facilitates the generation of comprehensive suitability or decision surfaces, providing a holistic view of the spatial variations and trade-offs involved.

However, there are considerations and limitations to be aware of when using weighted overlay. The weights assigned to criteria represent the decision-maker's preferences and priorities and can significantly impact the outcomes. Therefore, the weighting process should be cautiously approached and involve stakeholders' input and consensus. Additionally, the weighting method can influence the results, and decision-makers should carefully select an appropriate method based on the decision context and available information (Malczewski, 2006).

4.4.3. Random Forest Classification

Random Forest (RF) classification, a classification method that Friedman independently described, is an ensemble learning method used for classification and regression. In a standard tree, each node is separated using the best separation score considering all predictor variables. However, using an ensemble learning method in a random forest, each node is divided using the most desirable score between a subset of predictors randomly selected at each tree node. Ensemble classifiers use randomly chosen subsets of training data[23] and features to generate several regression classifiers and aggregate the predictions of individual trees to make a final classification decision (Friedman, 1976; Breiman et

[23] The training process involves selecting relevant features from the dataset, dividing the dataset into training and validation subsets, and constructing multiple decision trees based on random subsets of the training data. Each decision tree is trained independently using a different subset of features and data instances. The trained model can then classify new data and generate a spatial output representing the relative suitability or predicted surface (Fisher and Cutler, 2020).

al., 1984; Quinlan, 1986; Breiman, 2001; Misra and Li, 2020)[24]. Each decision tree independently assigns a class to a cell (i.e. each tree has one vote), and the majority of votes defines the final class (Breiman, 2001) using voting or averaging techniques to generate the final output. A depiction of how RF works is included in Figure 11.

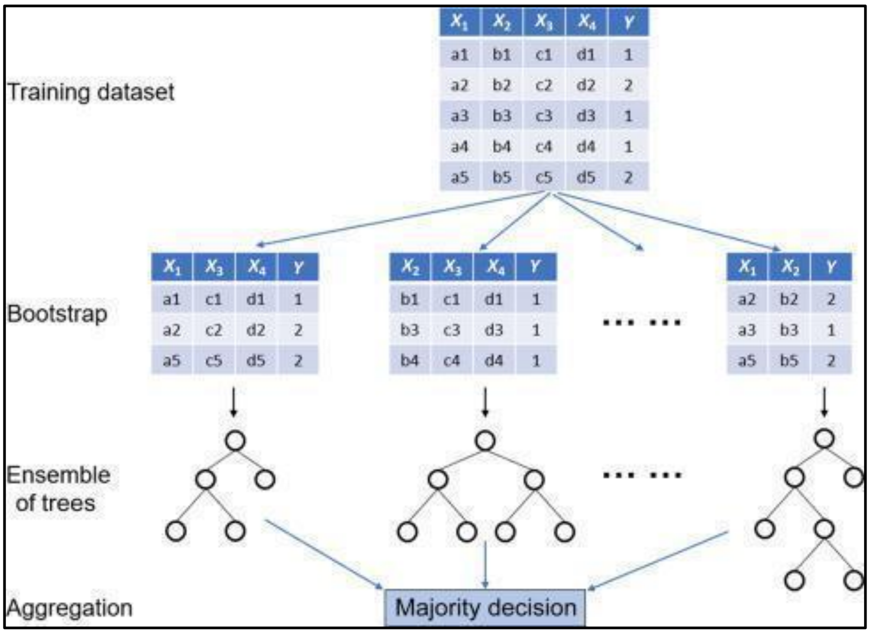


Figure 11: Implementation of RF classifier on a dataset that has four input variables (X1, X2, X3, and X4) and predicting Y, which has two classes (Y=1 and 2). Source: Misra and Li (2020).

RF classification uses several aggregation techniques to aid the prediction of individual trees. However, the two best-known methods applied for the aggregation of values are boosting and bagging of classification trees. In the boosting aggregation technique, consecutive trees add extra weighting to the points that previous predictors incorrectly predict, and upon completion, a weighted vote is used for prediction. For bagging (bootstrap aggregating, proposed by Breiman (1996), used in RF classification, a random forest tree is constructed using a bootstrapped data set. It includes randomly selected cases (cells) from the training data set introduced independently by Ho (1995), Ho (1998) and Amit and Geman (1997), allowing replacement and duplicates. However, this also provides for constructing a collection of decision trees with a controlled variation. Thus, subsequent trees do not depend on previous trees; each is independently constructed using a bootstrap data set sample. This technique uses a simple majority vote prediction, providing extra randomness to bagging. Apart from the creation process (each tree uses a different bootstrap sample of the data), random forests use different tree construction methods (Naidoo, 2017; Misra and Li, 2020).

[24] The combination of multiple decision trees improves the accuracy and robustness of the classification model.

This leads to uncorrelated trees with reduced computational capacity (Gislason et al., 2006). The default value for mtry is the square root of all variables (Breiman, 2001). Random forest uses the Gini index to measure impurity and select each node's best splitting feature. Typically, approximately two-thirds of the data is used for building the trees (Liaw and Wiener, 2002), and the remaining one-third (the"out-of-bag" (OOB) samples) may be used to validate the random forest (Breiman, 2001). At each node, a random subset (mtry) out of all variables M (i.e., bands) is considered to split data, whereby all trees are fully grown without pruning as a default approach. The decision trees can also be pruned to limit their depth (Breiman, 2001). OOB samples down every tree, which they were not previously part of, revealing the OOB error (cross-validation) and the proportion of OOB samples incorrectly classified (Gislason et al., 2006). Therefore, it is possible to identify the best ntree and mtry combination with the lowest error rate (Adam et al., 2014). Compared to other ensemble classifiers, for example, those using boosting, random forest is computationally simple and rapid while achieving similar accuracy. It can handle large numbers of variables without expanding the computation time required (Rodriguez-Galiano et al., 2012). RF is also advantageous as it does not overfit data and is relatively robust to outliers, missing values and noise (Breiman, 2001; Rodriguez-Galiano et al., 2012). Random forest is also very user-friendly as there are only two tuning parameters (ntree and mtry) (Liaw and Wiener, 2002). It can thus be used to estimate variable importance (Liaw and Wiener, 2002). However, it is still a black-box model (Gislason et al., 2006). Furthermore, using the random forest classifier has received increasing attention due to the excellent classification results and processing speed (Rodriguez-Galiano et al., 2012; Du et al., 2015). While recognised as a machine learning technique, it has also been used for multicriteria analysis in GIS[25] by training the algorithm on a labelled dataset (trained dated) that includes spatial and attribute data.

The end product of an RF is a classification map that shows the predicted class for each cell based on the majority of votes. As a by-product, it also generates a probability map for each class, which indicates the likelihood that each cell belongs to a specific class—for example, a high prediction rate results in a high-class probability and vice versa. Thus, information regarding the uncertainty of the classification is also provided (Sideris et al., 2019). Furthermore, this classifier can successfully select and rank those variables with the greatest ability to discriminate between the target classes. This is an important asset given the high dimensionality of data such as remotely sensed datasets, which makes selecting the most relevant variables time-consuming (Körting et al., 2013), error-prone, and subjective tasks (Belgiu et al., 2014). Nevertheless, while the random forest classification has proven its capacity to deal with large datasets and non-linear relationships and interactions amongst criteria (Fisher and Cutler, 2020), it

[25] Several studies have used RF classification and a MCDA technique. For example, Aramberi et al., (2019), use RF classification together with logistic regression and boosted regression to model erosion susceptibility.

remains unstable with the introduction of small disturbances in training data. Therefore, some studies have introduced fuzzy logic to random forest classification due to its intrinsic elasticity, which further offers a solution to the instability mentioned above (Bonissone et al., 2010).

4.5. GIS-BASED FRAMEWORK APPLICATIONS IN URBAN AND MINING-RELATED RESEARCH

Over the years, fundamental advances have been made towards integrating various data and GIS. While initially based on empirical foundations, GIS has since evolved to incorporate space-time geographic information (Goodchild, 2012) and geographically referenced information into conceptual frameworks used in the social sciences (Goodchild and Janelle, 2010). Harvey (2018) adds that the fourth industrial revolution makes adopting technologies, such as GIS, all the more important for spatial planning. Spatial planning encourages the rational organisation of activities associated with various facilities. It involves planning land use, determining conditions for arranging and locating activities, and identifying methods for improving existing and planned physical structures. This provides a framework for integrating multiple layers and variables, which is essential for gaining new insights into spatial relations and places' historical and morphological conditions (Page and Ross, 2015). Thus, using GIS-based frameworks is beneficial in regions with a rich and complex spatial history, such as mining and urban landscapes, where such spaces' characteristics and spatial patterns can be unified (Hillier, 2010; Alp and Guchan, 2017).

Several studies use GIS frameworks to integrate and document spatial features (He et al., 2015; Sang and Piovan, 2019; etc.). Several frameworks provide guidelines for the development of spatial frameworks at different scales. Existing frameworks were reviewed to assess the gaps and or suitability for diverse landscapes, primarily using the research objective of the study. Carrion et al. (2009) developed a framework for Land Planning and Management activities in India, including a large variety of datasets of heterogeneous typology, fundamental for diversified queries. Spaliviero et al. (2019) discuss a Spatial Development Framework (SDF) developed specifically to serve countries with weak planning systems facing rapid urbanisation from 2010 to 2011. The SDF was applied in Darfur (Sudan) between 2011 and 2013 and later improved and applied in Rwanda for the first time between 2014 and 2016. The study demonstrates the applicability of an SDF for analysing a system of human settlements in a given territory, evaluating the spatial structure of such a territory that empirically emerges from the analysis, and formulating strategic spatial planning recommendations or development actions according to the identified priorities. A study by Carjens et al. (2003) describes a GIS-based support tool, the Strategic Tool for integrating Environmental aspects in Planning Procedures (STEPP), developed for the Netherlands that incorporates environmental aspects in local spatial planning processes. The GIS-based STEPP tool aims to improve the coherence between spatial and environmental policy at the local level by stimulating the exchange of relevant information among involved disciplines and decision-makers while also providing a means for exploring alternatives.

However, most of these frameworks are useful in investigating individual landscapes and integrating data on a particular aspect of the landscape, such as the environment, culture or heritage. Several studies (e.g. Harmsworth, 1999: Hessel et al., 2009; Brown et al., 2012; Brown and Weber, 2012; Fagerholm et al., 2012; Klug, 2012; Brown et al., 2015; Wang et al., 2015; Brown et al., 2018) consider the practical integration of the tangible and intangible characteristics of a space. For example, Harmsworth (1999) uses a GIS framework to integrate indigenous knowledge systems with biophysical information to inform environmental planning efforts. While other studies (Hessel et al., 2009; Brown et al., 2012; Brown and Weber, 2012; Fagerholm et al., 2012; Brown et al., 2015; Brown et al., 2018) use community mapping approaches to incorporate community knowledge systems into land use and zoning planning. Klug (2012) uses the Leitbild[26] methodology as a framework to integrate the natural, social, economic and political characteristics of a landscape for a model of an aspired future landscape, which can be represented in GIS. Jackson et al. (2013) also developed a GIS framework to explore spatially explicit synergies and trade-offs amongst ecosystem services to support a multi-faceted landscape called a ‘polyscape’. In their study, Jackson et al. (2013) developed a multi-criterion GIS using participatory mapping to assess land-use suitability and support land-use planning (site level) from five perspectives of land attributes: physical, locational, social, economic, and environmental. The frameworks mentioned above and applications of GIS would be applicable in the context of Gauteng, where there is a need for an integrated understanding of the landscape as a whole, considering both the urban and post-mining characteristics of the landscape.

4.5.1. Applications of GIS-based frameworks in urban landscapes studies

Several studies have used GIS frameworks for documenting and analysing urban landscapes. For example, Siebert (2000) documents and visualises the spatial history of Tokyo using a GIS-based framework. Siebert (2000) finds that although sometimes objective, GIS is effective for the integration and visualisation of the characteristics of spatial features through time. According to Vannieuwenhuyze

[26] “A Leitbild (pl. Leitbilder) is a summary statement describing a desired and releasable future state for a specific issue or spatial unit, which takes account of the primary objectives and drivers in a holistic and integrated way. All present knowledge is used to balance future constraints and demands from social, economic, cultural, political and environmental perspectives. Therefore, a commonly accepted Leitbild projects a specified trajectory for the future spatial structure, distribution, utilisation, condition and development of the socio-natural system. It provides a set of guidelines that shape actions, and a framework within which the impact of particular developments can be judged and socially negotiated” (Klug, 2012: 617).

(2019), when seeking to understand their urban past better, most scholars consult 19th-century cadastral maps. Similarly, Siebert (2000) also notes that integrating various sets of historical and contemporary data in GIS gives insight into underlying relationships of social, demographic, economic, political, cultural, physical and other phenomena defining a landscape. Some other studies have investigated the applications of GIS frameworks in culture conservation and heritage management. For example, Alp and Guchan (2017) have investigated the benefits and drawbacks of using GIS frameworks in documenting and analysing the conservation of cultural properties of heritage sites in Bursa, Turkey. Alp and Guchan (2017) reported challenges such as data incompatibility, data gaps limiting analytical findings and technological shortcomings preventing capturing all historical content. There were also advantages, such as the framework's applicability in spatial and temporal analysis of heritage interventions.

Similarly, Giannopoulou et al. (2014) use an integrated GIS environment to link spatial data of the urban context together with the non-spatial features of the Old Town of Xanthi, Greece, to enrich the existing methods used to model the urban process and its impact on heritage regions. This study found that using an integrated GIS environment improves the quality of research and offers the possibility of continuously updated information and monitoring of the factors that influence development policies' implementation. Adopting an alternative lens, He et al. (2015) use a GIS framework to record and analyse physical and cultural heritage across different scales. The findings from this study are beneficial for demonstrating the incorporation of intangible and historical spatial phenomena into such models by defining relationships and connections between different levels of the underlying database. Similarly, other studies have investigated the applications of GIS frameworks in improving planning efforts and harmonizing relations between various spatial features. For example, Page and Ross (2015) use GIS frameworks to investigate the state of American cities before the 20th century. They argue that GIS frameworks are not only important for understanding the past but are also an invaluable tool in contemporary planning efforts, in particular for improving accessibility as well as the quality of urban space.

Furthermore, other studies use GIS frameworks to inform urban planning decisions. Wang et al. (2015) use a GIS-based framework to assess land use suitability and support sustainable planning in urban renewal. The framework proposed by Wang et al. (2015) effectively supported land use planning in urban renewal, as it provided a quantitative approach to suitability analysis and incorporated general information into land-use decision-making[27]. While other studies (Hessel et al., 2009; Brown et al.,

[27] However, Wang et al. (2015) also note that the proposed framework also had some limitations as not all the factors identified for incorporation could be quantified and socio-economic information was not incorporated into the framework.

2012; Brown et al., 2018; Fagerholm et al., 2019) use participatory geographic information systems (PGIS)[28] mapping approaches in their evaluation of landscape services and the integration of these data for various analyses in GIS. Another study by Harmsworth (1999) uses a GIS framework to preserve Maori traditional knowledge systems in New Zealand. Harmsworth (1999) integrates Maori values and biophysical information as an environmental management and planning tool. The findings of these studies indicate the applicability of PGIS in informing land use planning, zoning and valuing exercises. A recurring theme within these studies is the need to integrate ecosystem values into land use planning support (Brown et al., 2015).

4.5.2. GIS frameworks in post-mining landscape studies

Similarly, the mining industry saw an increase in the use of various digital technologies, such as spatial mapping and electronic data collection tools for modelling the prospectivity of minerals, made easier by the availability of GIS software in the 1980s. Today, the mining sector faces many more digital advancements in the advent of the fourth industrial revolution (Harvey, 2018). GIS is becoming increasingly important for spatially varying activities such as mining and related activities as it can be used not only to provide answers on ongoing benefits of mining activities but also to provide indications as to where and when mining activities are most beneficial across space and time (Swetnam et al., 2011; Choi et al., 2020).

While most studies use GIS to manage mining environments (Antwi and Weigleb, 2008; Karan et al., 2016), other studies, such as Choi et al. (2020), focus on investigating the impact of mining on the surface or how they can inform the restoration of mining areas to their original states. Computers and related software have also been utilised in the mining industry as tools for information dissemination, learning, collation and storage, strategic planning, networking (Pert et al., 2015), analysis of mining data and facilitating the design of mine operations (Buczyńska, 2020; Choi et al. 2020). Some studies such as Dixon (1999), Didier (2008), and Wężyk et al. (2015) using GIS in the management of mining areas have focused on integrating various spatial data for informing decisions on safety and risks in mining and urban environments. Dixon gathers data and investigates the potential for developing a GIS system for the Lime Creek mining region in Canada to assist in analysing and compiling safety reports. Didier (2008) investigates the French State's post-mining management efforts and potential applications of a database that captures and gathers data (locality, ownership and technical information) for use in screening risk and informing urban planning efforts. However, despite the use of spatial data

[28] PGIS refers to the public participation practice entailing the use of community mapping practices to generate spatial information (Brown et al., 2018).

and the availability of computer software within the mining industry, further development or use has been restricted by the availability of such data.

Gauteng is a case where such advancements in available software and data applications are still lacking. Data on urban-related concepts is most widely accessible, for example, through biennial land use data from the Department of Environmental Affairs and other data custodians who make it publicly accessible through online platforms. However, while some data on mining-related aspects of the Gauteng landscapes is available from land use data, most are inaccessible. The inaccessibility of mining-related data has been widely reported in many publications (Heath, 2009; CER, 2012; GDARD, 2009, 2012; Bobbins and Trangos, 2018; Watson and Olalde, 2019; Crous et al., 2020); this study responds to the gap mentioned above by proposing a framework for the integrated analysis, mapping, visualisation and conceptualisation of the characteristics of Gauteng's post-mining and

4.6. SUMMARY OF THE CHAPTER

This chapter has presented the findings of a survey of literature conducted to gain an overview of GIS and its applications in urban and mining landscape research. The chapter introduced GIS as an essential tool for the representation and visualisation of spatial information, also revealing GIS as a versatile tool with applications across various disciplines. This chapter then discussed the critiques of GIS, demonstrating that an integrative GIS could be more critical and act as more than a tool, but playing an essential role in the production of space and how it is understood. This was done to establish a context for this research project, which interrogates the representation of Gauteng's post-mining and urban landscapes. The chapter then discussed MCDA and its applications in a spatial context. The chapter noted the different methods used in multicriteria analysis and their structured approaches and applications in spatial problems such as land use suitability. This chapter then discussed GIS-based frameworks and their applications in representing spatial features. It also outlined the applications of integrative frameworks in studies related to urban and post-mining landscapes. GIS-based frameworks were revealed to be useful not only in the storage of integrated data but also shown to be useful in the management of areas under study. This chapter also highlighted the need for an integrative framework for the post-mining and urban landscapes in Gauteng, echoing other studies referencing limited data availability and the potential applications of an integrated framework.

CHAPTER FIVE: RESEARCH DATA AND METHODOLOGY

5.1. INTRODUCTION TO THE METHODOLOGICAL APPROACH

This chapter introduces the methodological design and specific research methods adopted in this study. To achieve this study's main aim and research objectives, this chapter introduces the process followed in the framework development, research process, and the selection of research methods. This research chooses six main research methods, including documentary and content analysis, an online questionnaire survey, a case study, GIS data collection and experimental studies by applying different multicriteria mapping techniques. Among them, literature and document review and survey results analysis are used to achieve Objective 1; literature, document and survey results review and GIS and experimental study are used to achieve Objective 2; and findings from Objectives 1 and 2 are used to inform and achieve Objective 3.

5.2. FRAMEWORK DEVELOPMENT PROCESS

The design of the proposed GIS-based framework follows a systematic approach comprising several key steps outlined in Figure 12. Broadly, the development of the framework was divided into two main parts: the first part pertains to the conceptual development of the framework, and the second part was the testing and validation of the framework.

The conceptual development stage entailed identifying objects and setting clear goals for the framework. The identification of objectives was followed by a comprehensive literature review to gather knowledge and insights from existing studies and frameworks, followed by the analysis and organisation of emergent themes to identify shared concepts and characteristics and the development of a conceptual framework outlining the core components and relationships of the framework. The testing and validation stage of the framework development had four main phases. Starting with data collection to acquire relevant spatial and non-spatial data, data processing and analysis to extract meaningful information from the collected data, the development of a practical framework - incorporating tools, methodologies, and guidelines for GIS implementation and the validation of the framework, ensuring its effectiveness and efficiency through testing and evaluation. Finally, the framework was finalised, considering insights from validation and making necessary adjustments.

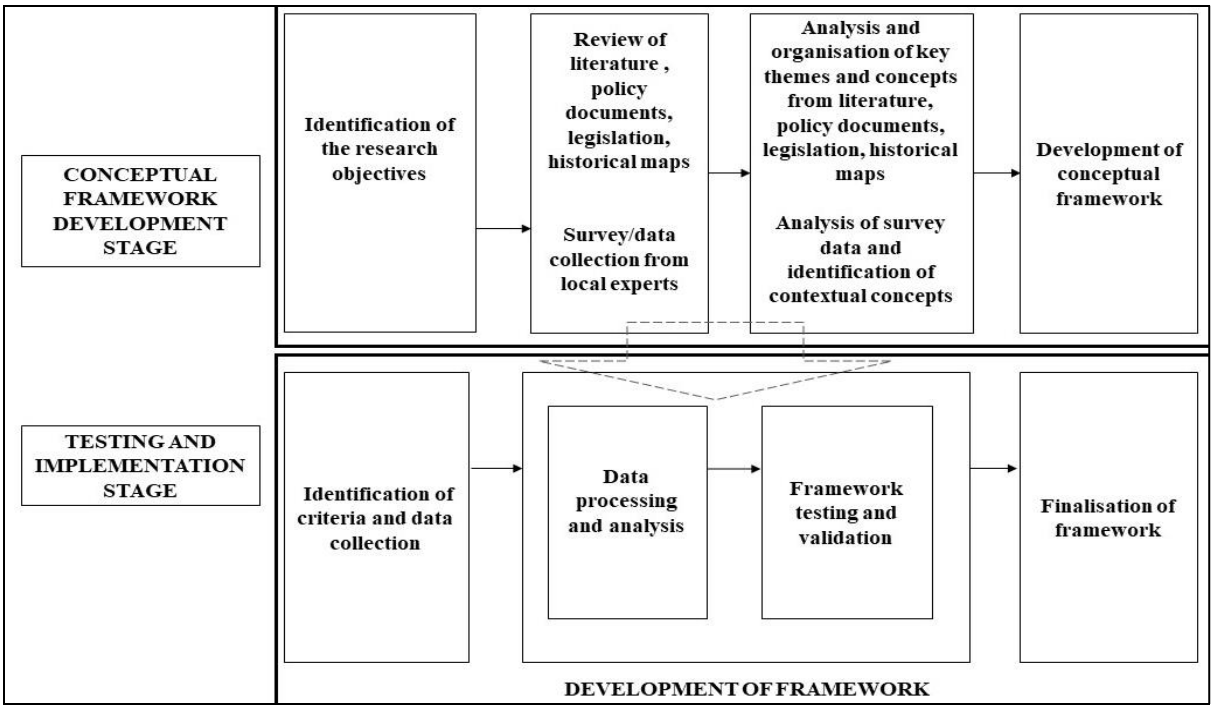


Figure 12: Framework development processes followed in this study.

5.3. RESEARCH DESIGN

The research entailed several research methods to meet the study's main aim and objectives. In this research study, a methodology was designed and employed to acquire an integrated understanding of Gauteng's urban and post-mining landscape. Specifically, an applied spatial framework using GIS technologies was conceptualised, developed, and validated to offer a flexible tool to support the integrated mapping of urban and post-mining landscapes in Gauteng. Given the nature of the methodological paradigm, empirical approaches used in the social sciences (such as surveys, case studies, and experiments using statistical and spatial analysis and machine learning) are applied to this research.

This research aimed to quantitatively analyse and support the holistic conceptualisation and mapping of the Gauteng landscape to fill the gaps identified by the literature. However, this subject is highly related to the social and environmental sciences and urban development, where the qualitative description of planning and development challenges is indispensable to reflect the planning goals of social and environmental interests. Therefore, this study used a mixed research methodology approach, including quantitative and qualitative methods. The data collection procedures of each research approach are outlined in Table 5.

Table 5: Data collection methods in quantitative, qualitative and mixed methods research. Source: Adapted from Creswell (2003).

RESEARCH METHOD	**DATA COLLECTION AND ANALYSIS ASSOCIATED WITH THE RESEARCH METHOD**
Qualitative Research Methods	● Emerging methods ● Open-ended questions ● Interview, observation, document, and audio-visual data ● Text and image analysis
Quantitative Research Methods	● Predetermined ● Instrument based questions ● Model performance, attitude, observational, and census data ● Statistical analysis
Mixed Research Methods	● Both predetermined and emerging methods ● Both open- and close-ended questions ● Multiple forms of data drawing on all possibilities ● Statistical and text analysis

Qualitative research approaches are subjective and collect data in the form of written and spoken language and observations recorded in a language that is analysed by identifying and categorising themes (Creswell, 2003). A qualitative research approach was followed in this research in the collection of survey data from local experts and content analysis from various documents. Despite the possible limitations that come with the use of these data, such as response bias, different perceptions from people, timeous data collection and inaccurate information collection (Halperin and Heath, 2016), they were chosen for use because they provide researchers with first-hand time-series, and thoughtful information that does not require time or money for transcribing (Creswell, 2003). The collection and analysis of the survey data using qualitative methods are discussed in section *5.4.1. Identification of post-mining and urban landscape characteristics*.

Quantitative research approaches are objective, collect data in numbers, and adopt statistical data analysis (Halperin and Heath, 2016). This research method was used through the applications of GIS to map the landscape characteristics under investigation and in the validation of mapping results. The methods used for the mapping and validation are discussed in sections *5.4.2. Development of practical framework: Methods used to map post-mining and urban landscape characteristics* and 5.4.3*. Testing and validation of the proposed framework*

5.4. RESEARCH METHODS AND INSTRUMENTS ADOPTED

Each research method and instrument adopted within this research study are discussed below. This section is divided into four parts, guided by the study's research objectives. The first part discusses the process for identifying landscape characteristics of post-mining and urban landscapes. The second part discusses data collection that was used to map the identified landscape characteristics of post-mining and urban landscapes. The third part discusses the use of Gauteng as a case study.

5.4.1. Identification of post-mining and urban landscape characteristics

The first objective of this study was to identify and assess various types of literature and data for their role in the conceptualisation of Gauteng as an urban or post-mining landscape. The key characteristics of these two landscapes were identified from the literature and archival material, including legislative and policy documents, to understand how Gauteng's post-mining and urban landscapes are conceptualised.

Both landscapes' landscape characteristics were identified using primary and secondary data sources. The data required for this study have been acquired in several ways. First, the secondary data was collected through the review of documents (in the form of literature, maps, legislation, etc.) and content analysis. This was followed by collecting primary data through an online questionnaire survey explicitly developed for this research study. Both of these data collection steps are discussed below.

5.4.1.1. Documentary and content analysis

Document analysis is a kind of archival research where the data sources are various types of documentation, such as academic papers, policy and legislation documents. Archival research entails any research where a public record is a unit of analysis (Dane, 1990) and attempts to interpret the research problem by investigating a portion of the continuously recorded information they create, such as written, graphic and audio-visual materials. A comprehensive review of multidisciplinary literature on post-mining and urban landscapes, in the form of academic papers and official documents such as legislation, including relevant policies on mining regulations, urban development, administrative regulations, and planning standards and guidelines, was conducted in this research.

The literature consulted was in English and obtained from the Web of Science, Science Direct, JSTOR, Wiley Online Library, Google Scholar and Google Search using key terms: 'Post-mining landscapes', 'Post-extractive’, 'Urban landscapes', 'GIS', 'Geographical Information Systems', Mapping' and 'Characteristics'. This established the existing research body and provided a strong foundation for this review. These keywords helped identify relevant literature to achieve the objective of this study. Initially, 493 potential literature sources were identified, followed by a selection process of the relevant material. From the identified sources, 317 were excluded from the study when found not efficiently to operationalise the keywords mentioned above. Of the remaining 176 articles, 23 were removed for duplication. The last step for including and excluding identified sources entailed reading abstracts and skimming through the remaining articles, where 30 were removed. The remaining 146 sources comprised academic papers, books, conference papers, industry research reports, policy and legislation documents and spatial data and were read in full and applied in the documentary analysis. Table 6 shows that 134 academic papers were identified and consulted in addition to two conference papers, eight historical maps, ten industry research reports, six policy and legislation documents and 12 spatial datasets. Careful attention was paid to their descriptions and representation of post-mining and urban landscapes and their characteristics.

Table 6: Quantity of documentary sources consulted and reviewed.

SOURCES CONSULTED	**COUNT**
Academic paper/book	134
Conference paper	2
Historic map	8
Industry research report	10
Policy and legislation document	6
Spatial data	12
Total	**172**

The documentary analysis of the literature review material was used to identify emergent themes (Miles and Huberman 1994). Miles and Huberman (1994) suggest coding the emergent themes using qualitative research tactics to generate meanings from different texts. Key themes can be simplified through coding and identifying independent concepts (Jabareen, 2006, 2009). Keywords and the characteristics used to describe post-mining and urban landscapes were recorded for each reading on separate Excel worksheets for post-mining and urban landscapes, respectively.

5.4.2. Online survey and interviews with local experts

According to Dane (1990), an interview is a structured conversation based on an underlying survey, where the survey devises the structure of the conversation to collect data. Interviews can be conducted through various means, including in-person, by telephone or email. One of the most prevalent interview types is the expert interview, featuring individuals who are experts in a research area or have extensive experience relevant to the research problems tackled in a study. This study makes use of local experts to inform the study. "Local expert" in this research study refers to academics, environmentalists and planning practitioners with experience or related research on urban and post-mining landscapes.

A survey with local experts was considered the main research instrument for its efficacy in collecting in-depth, practical and up-to-date information. Survey research is universal in that respondents are asked questions directly. The questions may be raised in an interview or presented as a questionnaire (Dane, 1990; Halperin and Heath, 2016). In questionnaire surveys, participants are asked to complete a questionnaire by answering questions. The surveys were employed to collect qualitative data that could be quantified and used for statistical analysis at a later stage. This research method was applied to collect the initial expert responses describing characteristics of urban and post-mining landscapes for quantitative and qualitative analyses.

The questions in the survey aimed to get insights into the conceptualisation of post-mining and urban landscapes, where these conceptualisations come from, and the critical issues with the current conceptualisation of post-mining and urban landscapes. Additionally, the survey (and later interviews) conducted with local experts were helpful in investigating how urban and post-mining landscapes are characterised in Gauteng, identifying existing problems in the conceptualisation practices and helping identify key factors/criteria affecting the characterisation and conceptualisation of post-mining and urban landscapes.

5.4.1.2.1. Designing the questionnaires

The survey taken by local experts was developed online using Google Forms, and a consent sheet was made available on the survey. The participants signed and uploaded the consent sheets to the survey document. The survey was conducted electronically due to the South African COVID-19 lockdown regulations. However, later in the data collection, interviews were also introduced. As such, data was collected in two ways, using a Google Forms survey and later interviews conducted with five additional local experts when the response rate was low[29]. The interviews with experts were conducted when participants experienced technical issues or could not complete the questionnaire online. Consent for the interview input was acquired verbally and recorded, after which participants were sent transcriptions of their responses and a consent form to fill in and send back. This was required for comparison with the key characteristics tentatively identified by the literature review.

The survey was divided into two sections, one more general, requiring information on the participant, and the other comprising research questions. The survey was further divided into questions of a spatial nature, aimed at experts with spatial and GIS knowledge and those with mining or post-mining and urban landscape knowledge. As such, the survey also allowed the experts to skip some questions that did not apply to them. The survey asked participants whether or not they use GIS in their line of work. Although the questions are similar, participants indicating that they work with GIS received more technical questions than those who reported not using GIS. The questionnaire was sent to 40 potential participants in local municipalities, government agencies, academia and relevant research spaces.

Before the survey was administered, the pilot survey was sent to four local experts, two with GIS knowledge and two without. The main aim of the pilot survey was to identify the following:

[29] The responses from these respondents were then transcribed in the format of the survey responses.

- The duration of the survey;
- The clarity of the instructions and questions and;
- Issues or any objections to any of the questions asked.

The respondents' comments were considered before the questionnaire's finalisation. The questionnaire sample is available in Appendix 1.

The questions in the questionnaire were open-ended, so the responses were as close as possible to participants' perceptions. The questionnaire survey comprised questions covering the following topics:

- Conceptualisation (characterisation of post-mining and urban landscapes in Gauteng with an emphasis on existing historical and contemporary documentation);
- Cartographic representations of mining, post-mining and urban landscapes;
- Influence of mining and post-mining landscape mapping on surroundings and urban development trajectories.

The questionnaires were submitted to the University of the Witwatersrand's Human Research Ethics Committee (Non-Medical) for approval before the commencement of the research study. The ethics protocol number was H20/06/15 (see the ethics certificate in Appendix 2).

5.4.1.2.2. Sampling and distribution of questionnaires

The second, a snowball sampling technique, was used where the approached participant referred to another potential participant. Two sampling methods were employed to identify participants for the study. Participants for this study were selected using convenience and snowball sampling methods. First, a convenient sampling technique, where participants were identified based on knowledge of similar work or research. Some participants were identified from workshops on similar research or references from other participants. A desktop study was conducted to collate contact details for each identified participant, particularly email addresses. Emails were sent to the identified individuals, with the survey link attached and a proposed completion date. The survey responses were automatically uploaded onto a Google Drive folder online, along with the participant consent forms.

The survey was sent to participants over three months in 2021, with follow-up questions necessary in July 2022. The survey was run in two sets, first from 01 to 15 July 2021, where the survey was sent to four participants, and a preliminary analysis of responses was conducted. Afterwards, the survey was sent to more participants from 01 August to 30 September 2021. However, the survey completion was relatively low during the second round, and some responses could not be used. Overall, the survey and the interviews yielded 26 responses from local experts (Table 7) that could be used.

Most participants (10) were from academic institutions, followed by eight from the private sector and four from a local or provincial government department and other sectors.

Table 7: Participant profile of experts and their industries.

TYPE OF ORGANISATION/INSTITUTION	NUMBER OF SURVEY PARTICIPANTS
Local or national government department	4
Academic institution	10
Private sector	8
Other	4
Total	**26**

Although this was a small sample size, there was a good spread of participants spanning different sectors, including those working in/for government, academia and the private sector, giving a fair representation of stakeholders and experience. The experience of the local experts varied, where most had over five years of experience working in related fields, while the least experienced had a little over three years of experience.

Figure 13 shows participants with experience in environmental studies, architecture and urban planning, and social and heritage-related work participated. Figure 13 also shows that most of the participants (38%) were from academia, followed by environmental practitioners (19%), participants with a planning background (15%), engineering (12%) and participants who worked in advocacy and social impact-related industries (8%).

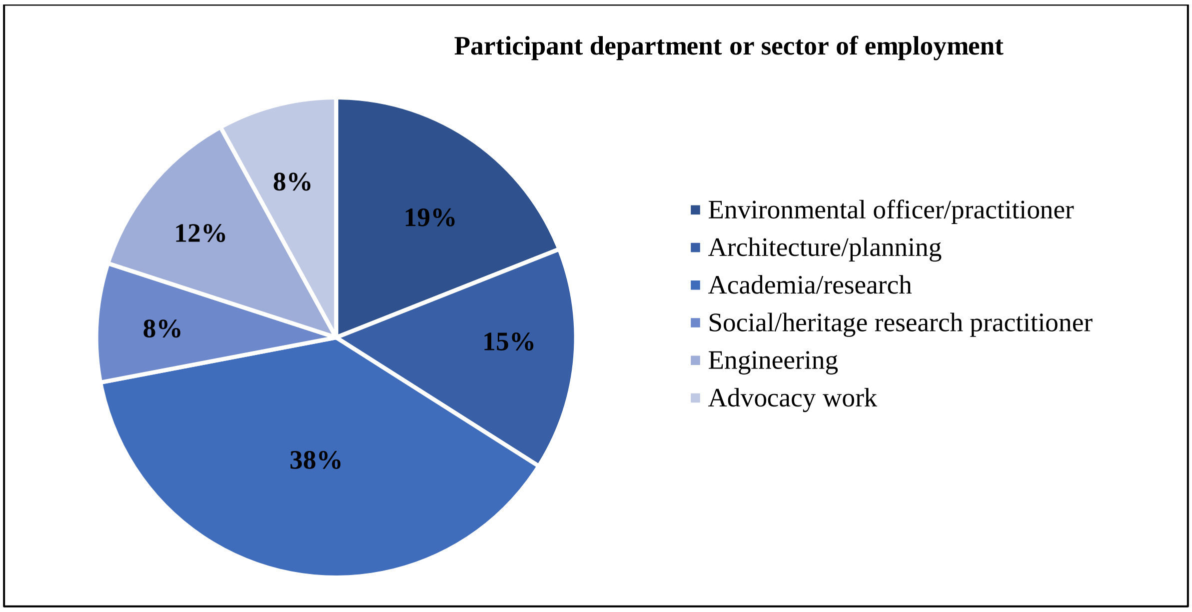


Figure 13: Participant industry or sector of employment.

5.4.1.2.3. Analysis of data collected for requirements identification

The data acquired from documentary sources and through the online questionnaire surveys were analysed using Microsoft Excel® software (2016) – herein Excel. The questionnaire survey responses were downloaded online as an Excel spreadsheet listing participants' responses. The Excel spreadsheet was formatted so that each question could be considered as a variable and could be analysed. Several questions were examined in frequency tables; for example, the participant information in Table 7, participant industry information in Figure 13 and questions relating specifically to the characterisation of post-mining and urban landscape characteristics were analysed. The results of the analysis are presented in Chapter 6. The identified characteristics were used to inform spatial data collection for mapping and modelling these landscapes.

5.4.3. Case Study

The case study is a valuable research method that can accommodate many investigations (Tellis, 1997a; Halperin and Heath, 2016). Case studies emphasise the context of a limited number of events or situations and their relationships, bringing out the details from the in-depth investigations with a full circle on the selected cases by using multiple sources of data (Tellis, 1997b). Yin (1994) suggests that a case study has four stages: 1) its design, 2) its conduct, 3) the analysis of evidence, and 4) conclusions developed from the case study, recommendations and implications. He also identified three types of case studies: exploratory, explanatory and descriptive. As a research tool, a case study of Gauteng province was used to practically develop a framework consisting of three major components: a conceptual model, a GIS model and an accompanying database based on the framework's structure conceptualised previously. The case study application in this research can be categorised into the ‘exploratory case studies' category. This is because this research used the case study of Gauteng to investigate the merits of integrating its post-mining and urban landscape characteristics. Actual spatial data on Gauteng and practical concerns (acquired from questionnaires) were involved in the case study, which aims to present the whole research process of a real case and demonstrate the merits and limitations of the proposed framework.

5.5. FRAMEWORK CONCEPTUALISATION AND DEVELOPMENT

Roy (1996) argues that MCDA is required to combine all characteristics in situations with contrasting characteristics. In a spatial context, spatial multi-criteria decision-making refers to the application of MCDA in a spatial context, where the elements involved in the decision-making process have specific spatial dimensions (Chakhar and Mousseau, 2007). As mentioned above, three mapping methods using a spatial multicriteria approach have been selected to evaluate the integration of landscape characteristics: Fuzzy overlay analysis, Weighted overlay analysis and Random forest classification.

Other steps in the framework development have already been discussed in previous sections, namely: the identification of research objectives in Chapter 1, the review of the literature and user needs, the analysis and organisation of landscape characteristics, data collection and data processing and analysis in Chapter 5. However, more details on the landscape characteristics are discussed in Chapter 6. This section discusses the development of the conceptual framework, data processing, data analysis and mapping, framework testing and finalisation (further discussed in Chapter 6).

5.5.1. Development of the conceptual framework

The development of the conceptual framework entailed the analysis and organisation of themes and characteristics emerging from the documentary and survey analysis and then making sense of it in the study context. All three mapping methods selected for implementing the proposed mapping framework entail breaking down characteristics and grouping them as indicators or criteria for analysis. To develop the proposed framework, the criteria were identified based on existing literature from planning theories and the survey data from local experts. The processes used in this study to identify criteria are discussed in section 5*.5.1.1. Identification of criteria or characteristics for mapping*, *5.5.1.2. Spatial data collection* and 5*.5.1.3. Data pre-processing and transformation*.

5.5.1.1. Identification of the criteria

The characteristics identified from the literature are listed in *6.2.1. Content analysis: Literature, legislation and other archival material, while the characteristics identified from local experts are listed in 6.2.2. Content analysis: Questionnaire evaluation: context-specific conceptualisations of urban and post-mining characteristics*. These characteristics were used to identify criteria that could be mapped and get a sense of the required data; after that, the spatial data considered most relevant or related to the characteristic was identified. The identified required spatial data based on the characteristics associated with post-mining and urban landscapes, layers for model input or mapping and the processing techniques were used to create the required landscape characteristics (Table 8). Definitions of the broader landscape characteristics are in Appendix 33-37.

Table 8: Landscape characteristics and spatial data requirements.

	NO.	BROADER LANDSCAPE CHARACTERISTIC	PROXY	CHARACTERISTIC FOR MODEL INPUT/MAPPING	SPATIAL LAYER RELATED TO LANDSCAPE CHARACTER
	1	Artificial	● Land cover/use change	● Mining-related cover/use	● Land cover/use change data
			● Built infrastructure	● Mining-related built-up areas	● Land cover/use data
	2	Assemblage	● Land cover/use change	● Mining-related cover/use	● Land cover/use change data

POST-MINING LANDSCAPES	3	Transformation	• Land cover/use change	• Mining-related cover/use (1990 • Mining-related cover/use (2020)	• Land cover/use change data
	4	Isolation and inaccessibility	• Accessibility	• More than 500m from roads • More than 1000m away from the railway	• Buffer of roads • Buffer of railway
	5	Density	• Population changes	• Low population density	• Population data
	6	Social impact and justice	• Unemployment	• Unemployment rate	• Unemployment data
	7	Economic development and decline	• Business/economic activity • Abandoned mines • Economic diversity	• Low business/ industry concentration • Abandoned mines • Lack of economic diversity	• Business and industry location data • Abandoned mines data • Active mines data
	8	Natural resource use and degradation	• Land degradation	• Land degradation • Land cover	• Low NDVI values • Land cover data: change to eroded, barren
	9	Integrative rehabilitation and management	• Rehabilitation • Mine waste	• Mining-related land cover/use • Activity within waste buffers	• Land cover/use data: change from mining to urban and other classes • Activity and development within waste buffers
	1	Artificial	• Land cover/use change • Built infrastructure	• Urban-related cover/use • Urban-related built-up areas	• Land cover/use change data • Land cover/use data
	2	Assemblage	• Land cover/use change	• Urban-related cover/use	• Land cover/use change data
	3	Transformation	• Land cover/use	• Urban-related cover/use (past) • Urban-related cover/use (present)	• Land cover/use change data
	4	Mutual mobility and accessibility	• Accessibility	• Less than 500m from roads • Less than 1000m away	• Buffer of roads • Buffer of railway

URBAN LANDSCAPE				from the railway	
	5	Density	● Population density	● High population density	● Population data
	6	Social impact and justice	● Inequality	● Unemployment rate	● Employment data: high unemployment
	7	Economic development and opportunity	● Business/ economic activity ● Economic diversity ● Employment opportunities	● High business/ industry concentration ● High economic diversity ● Unemployment rate	● Business and industry location data ● Land cover/use: Commercial/industrial data ● Employment data: low unemployment
	8	Natural resource use and degradation	● Pollution and waste	● Pollution and waste	● Land cover/use: Sewage/landfill data

5.5.1.2. Spatial data collection

Several studies (CER, 2012; GDARD, 2012; Bobbins and Trangos, 2018) have highlighted the limited accessibility of mining-related data. Therefore, this study uses primary and secondary data to develop a GIS framework for integrating Gauteng's urban and post-mining landscapes' historical and contemporary data and characteristics. The collection of spatial data identified in the requirements entailed several steps. All data used for this purpose was publicly available data. The data collected are presented in Appendix 2 and comprise different datasets, such as historical maps, spatial data on mines, shafts, voids or any recordings of operational and discontinued mining operations[30]. These data were used due to ease of access but also so that the exercises carried out within this research study could be replicable. This research utilises both primary[31] and secondary data. The data was collected per the characteristics and representational requirements identified as descriptive of the urban and post-mining landscapes outlined in Table 8. The secondary data was collected through a web and manual search for geospatial and non-geospatial data on post-mining and urban landscapes and is presented in Table 9.

[30] These were supplementary sources of information collected for this research's purposes, mainly used in identifying mining characteristics and not used in the actual mapping.

[31] Primary data was collected through a google forms questionnaire and interviews with industry experts. The results are presented in section *6.2.2. Content analysis: Questionnaire evaluation: context specific conceptualisations of urban and post-mining characteristics.*

Table 9: Spatial data collected for this research study.

NO.	SPATIAL LAYER	DATA FORMAT	EXTRACTED CLASSES / DATA	DATA SOURCES
1	Abandoned mines and shafts	Point/ Vector	Locations of abandoned mines/shafts	CGS (2013) SAMINDABA, DMR(2009)
2	Active mines	Point/ Vector	Locations of active and abandoned mines/shafts	DMR (2004, 2011, 2014, 2018)
4	SA NLC 2020	Raster	Artificial flooded mine pits, Artificial sewage ponds, Land-fills, Residential formal, Residential informal, Urban recreational fields, Commercial, Smallholdings, Industrial, Roads and rails (major linear)	DEA/GTI (2020) 2020 SANLC
	SA NLC 1990	Raster	Urban built-up, Urban township, Urban sports and golf, Urban smallholding, Urban residential, Urban informal, Urban school and sports ground, Urban industrial, Urban commercial, Mines 1 bare, Mines 2 semi-bare, Mines water seasonal, Mines water permanent, Mine buildings	DEA/GTI (2020) 1990 SANLC
	SA NLC 1990 – 2020 Class change	Raster	Changed from mines to barren land, changed from mines to built-up commercial, changed from mines to built-up industrial, changed from mines to built-up residential all, changed from mines to built-up smallholdings, changed from mines to commercial annuals non-pivot, changed from mines to commercial annuals pivot irrigated, changed from mines to cultivated subsistence, changed from mines to eroded lands, changed from mines to grasslands, changed from mines to natural wooded land, changed from mines to planted forest, changed from mines to shrubland, changed from mines to thicket / dense bush,	DEA/GTI (2020) 1990-2020 Land cover and land use class change data

			changed from mines to waterbodies, changed from mines to wetlands	
	Hexagon summary area-based land cover	Vector	Commercial, Industrial, Education, Healthcare Facilities, Institutions, Tourism, Community Services, Cluster housing, Formal housing, Informal housing, Recreation & Leisure, Utilities, Transport, and Built-Up	GTI (2020) Hexagon summary area-based land cover and land use
5	Census population data per Small Area	Polygon/Vector	Population statistics per small area	StatsSA (2011)
6	Census employment data per small area	Polygon/Vector	Employment statistics per small area	StatsSA (2011)
7	Gauteng main roads	Line/Vector	Main roads	CSIR (2018)
8	Gauteng railway	Line/Vector	Railway lines	CSIR (2018)
9	Mine residue areas	Polygon/Vector	Location and area of mine residues	GDARD (2009)
10	Gauteng pollution buffers	Polygon/Vector	Mine dumps, slime dams, general waste, general sewage, hazardous waste	GDARD (2016)

Once collected, the secondary data was stored in a geodatabase created for this study. The database used for storing data in this research was built in the environment of ArcGIS 10.3. The collected data were processed in one software module – ArcMap. The database was created as a File Geodatabase in another software module, ArcCatalog. All datasets were stored in a File Geodatabase created in ArcGIS (see Appendix 4).

5.5.1.3. Data pre-processing and transformation

Considering the integrative nature and analysis methods identified for application within this study, the data processing required in this study included three steps: (1) projection to the relevant coordinate system, (2) format and scale conversion and (3) spatial analysis and mapping of landscape characteristics in ArcMap 10.3. All data used in this study was projected to use the WGS 1984 UTM Zone 35S projection. Next, the format and scale of the data were converted so that all the data conformed to the same format and were, therefore, comparable. When presented with non-spatial data, the data was joined to a shapefile using a common field identifiable in both the shapefile and the Excel table using the ‘Join field’ Geoprocessing tool. The data within this study was of varying scales. Thus, this had to be changed to make the data comparable and fit for integration. Some scholars (such as Van Eetvelde and Antrop, 2009 and Liu and Nijhaus, 2020) suggest converting data into a standard format with similar units of study. To standardise the scale of analysis, all the data utilised within this study needed to be converted into a grid cell format.

First, a grid of 1 x 1 (1km^2) was created covering the study area[32]. The grid cell was created on ArcMap 10.3 using the ‘*Create Fishnet*’ Geoprocessing tool. Second, the data in a vector format, such as population[33], businesses, industries, unemployment rate, and abandoned and active mines, were created through a spatial join counting the sum of features per grid cell. The layers of locational attributes, such as distance to roads and railways, were vector layers, and the distance between roads and the railway was calculated using the “*Multi-Ring Buffer*” Geoprocessing tool. The resultant buffer rings were intersected with the fishnet grid, using the '*Intersect*' Geoprocessing tool, and later re-joined to the grid using the cells as the common field. Once re-joined, the fishnet grid was converted to a raster format using the ‘*Feature to Raster*’ Conversion tool, with a 1 km^2 cell size.

Following this, the raster data, extracted from the land cover/use[34] classes, such as the built-up class, were resampled[35] to the same resolution as the 1 km fishnet grid using the ‘*Resample’* Data management tool. The land cover and land use classes were extracted from the land cover and land use data using the “*Extract by attribute*” Spatial analyst tool. Similarly, a Normalised Difference Vegetation Index (NDVI)[36] (see Appendix 5) was created and resampled. The lowest scores from this NDVI calculation, below 0.5, were extracted using the “*Extract by attributes*” Spatial Analyst tool. The ‘Raster to Polygon’ Conversion tool converted all the extracted raster classes to vector data. The converted raster data were simplified and merged to reduce processing time and limit attribute entries using the “*Dissolve*” Geoprocessing tool. The converted data was then intersected with the fishnet grid using the '*Intersect*' Geoprocessing tool, joined using the *Spatial Join* to the fishnet grid and converted to raster using the ‘*Feature to Raster’* Conversion tool with a specified resolution of 1km^2 so that the data could be

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[32] This resolution was used as some of the data used in the study had a resolution of 1 km^2.
[33] Population density was derived from census population data and therefore contained the statistical information of population density per small area using a small areas layer.
[34] The land cover/land use data was created from imagery acquired in 1990 and 2020, these two layers were also accompanied by a change detection layer created using image differencing.
[35] Noting that although it has become conventional to resample data with different native resolutions to a common resolution, this has important drawbacks, which include introducing uncertainty in the model and sacrificing detail about the independent variables (Dixon and Earls, 2009).
[36] This was generated using a simple calculation on Raster Calculator, where the values of the Near Infrared band were subtracted from the Red band and divided by the same. The data was generated using data from Landsat 8 from 2021, as it had the least cloudcover for the study area.

comparable to the $1km^2$ fishnet grid and all the other processed data. All datasets were saved in a geodatabase (refer to Appendix 6).

5.5.1.3.1. Reclassification and ranking of data for this study

Once converted into a grid format and rasterised, all post-mining and urban landscape characteristics data were reclassified using the "*Reclassify*" Spatial analyst tool, using a scale of 1 to 9, as applied in AHP. In this scaling, 1 indicates the least important value of the data, and 9 is the most important. The reclassification values were adopted from literature, using literature guidance to distinguish whether some characteristics are present in post-mining and urban landscapes and to what scale. For example, while urban landscapes are accessible and should have higher access to roads and the railway, post-mining landscapes are not generally associated with accessibility. They are thus interested in those areas furthest from the road. Once all data had been reclassified, it was saved in a specific geodatabase (refer to Appendix 6). Table 10 presents how the characteristic layers were reclassified[37]. The reclassification levels noted in Table 10 were used to reclassify the characteristic layers in ArcMap 10.3. The reclassified characteristic data were used to map the landscape characteristics of post-mining and urban landscapes in section *6.4. Mapping post-mining and urban landscapes*.

Table 10: Reclassification scales of landscape characteristics.

NO.	**CRITERIA LAYER NAME**	**LANDSCAPE**			
		(POST)-MINING		**URBAN**	
1	Business count per km^2	✓	0 - 10 businesses (9) 11 – 20 businesses (8) 21 – 120 businesses (1)	✓	21 - 120 businesses (9) 11 - 20 businesses (2) 0 - 10 businesses (1)
2	Industry count per km^2	✓	0 - 10 industries (9) 11 – 20 industries (8) 21 – 654 industries (1)	-	21 - 654 industries (9) 11 - 20 industries (2) 0 - 10 industries (1)
3	Unemployment rate per km^2	✓	40 - 100% unemployment (9) 20 – 39% unemployment (8) 1 - 19% unemployment (1)	-	40 - 100% unemployment (1) 20 – 39% unemployment (5) 1 - 19% unemployment (9)
4	Active mines count per km^2	✓	1 - 10 businesses (9) 11 – 20 businesses (8) 21 – 22 businesses (1)	-	

[37] The levels of the reclassification were identified subjectively, guided by the characteristics identified from the literature. For example, several studies noted that urban landscapes and urban areas were characterised by high accessibility, therefore accessibility (access to roads and rail) had a high ranking. By contrast, studies suggested that post-mining landscapes were physically isolated, as such accessibility had a low ranking in mapping post-mining landscapes. The references used to inform the characterisation of each of the landscapes are listed in Appendix 33 and 37.

5	Distance to railway per km^2	✓	*Not within 1000m of the railway* 0 - 1000m away from the railway (1) 1001 - 2000m away from the railway (3) 2001 – 3500m away from the railway (5) 3501 - 5000m away from the railway (6) 5001m+ away from the railway (9)	✓	*Within 1000m of the railway* 0 - 1000m away from the railway (9) 1001 - 2000m away from the railway (6) 2001 – 3500m away from the railway (5) 3501 - 5000m away from the railway (3) 5001m+ away from the railway (1)
6	Distance to roads per km^2	✓	*Not within 500m of the road* 0-500m away from the road (1) 501-1500m away from the road (5) 1501- 2500m away from the road (6) 2501- 3500m away from the road (8) 3501m + away from the road (9)	✓	*Within 500m of the road* 0-500m away from the road (9) 501-1500m away from the road (8) 1501- 2500m away from the road (6) 2501- 3500m away from the road (5) 3501m + away from the road (1)
7	Historical land cover/use (1990) per km^2	✓	All mining-related categories (9) [mine water (seasonal), mine water (permanent), mines 1 (bare), mines 2 (-semi-bare) and mine buildings]	✓	All urban-related categories (9) [urban built-up, urban residential, urban sports and golf, urban commercial, urban formal, urban informal, urban school and sports grounds, urban township]
8	Present land cover/use (2020) per km^2	✓	All mining-related categories (9) [mines: surface infrastructure; mines: extraction pits and quarries; mines: tailings and resource dumps; and artificial flooded mine pits]	✓	All urban-related categories (9) [artificial dams, residential (formal), residential (informal), artificial sewage ponds, commercial, urban recreational and landfills]
9	Land cover/use change (1990-2020) per km^2	✓	All mining-related categories (9) [Increase and decrease of mining-related land cover/use]	✓	All urban-related categories (9)
10	Abandoned and derelict mine locations per km^2	✓	1 - 23 (9)	-	
11	Population density per km^2	✓	0 – 1000 people (9) 1001 – 5000 (8) 5001 – 66609 (1)	✓	5001- 66609 people (9) 1001 - 5000 people (5) 0 - 1000 people (1)

12	Mine residue and other pollution sources per km^2	✓	Radioactive mine residue (9) Other metals and precious stones (8) Other (1)	-	
	Urban waste per km^2	-		✓	Sewerage
	Rehabilitation per km^2	✓	Changed from mines to barren land (9) changed from mines to built-up commercial (9) changed from mines to built-up industrial (9) changed from mines to built-up residential (9) changed from mines to built-up smallholdings (9) changed from mines to commercial annuals non-pivot (9) changed from mines to commercial annuals pivot irrigated (9) changed from mines to cultivated subsistence (9) changed from mines to eroded lands (9) changed from mines to grasslands (9) changed from mines to natural wooded land (9) changed from mines to planted forest (9) changed from mines to shrubland (9) changed from mines to thicket / dense bush (9) changed from mines to waterbodies (9) changed from mines to wetlands (9)	✓	Changed from mines to barren land (9) changed from mines to built-up commercial (9) changed from mines to built-up industrial (9) changed from mines to built-up residential (9) changed from mines to built-up smallholdings (9)

5.5.2. Development of practical framework: Methods used to map post-mining and urban landscape characteristics

Based on the content analysis and local expert input, three mapping techniques were used to get a general picture of integrating post-mining and urban landscape characteristics. The results from these mapping exercises were used to gather insight into the integration of post-mining and urban landscapes and what a potential framework for their integration would entail. The visual representation of the proposed relations between the post-mining and urban landscape characteristics in Gauteng is presented in Chapter 6. This section discusses how the identified landscape characteristics data have been integrated using three mapping methods and how these methods were assessed for their applications and limitations. The section is divided into three parts: *5.5.2.1. Fuzzy overlay analysis of post-mining and urban landscape characteristics, 5.5.2.2. Weighted overlay analysis of post-mining and urban landscape characteristics and 5.5.2.3.Random forest classification of post-mining and urban landscape characteristics.*

5.5.2.1. Fuzzy overlay analysis of post-mining and urban landscape characteristics

Fuzzy Overlay was the first method explored in mapping urban post-mining and urban characteristics. It allows the analysis of the possibility of a phenomenon belonging to multiple sets in a multi-criteria overlay analysis. Fuzzy Overlay also determines the relationship between different sets of criteria. Fuzzy overlay, as described in section *4.4.1.*was chosen as the analysis method because it allows consideration of each criterion without arbitrarily limiting values.

This research study integrates Gauteng's post-mining and urban landscape characteristics. This section outlines the approaches to combining criteria building up to the final post-mining and urban landscapes fuzzy overlays in sections *5.5.2.1.1. Fuzzy overlay of post-mining landscape characteristics* and *5.5.2.1.2. Fuzzy overlay analysis of urban landscape characteristics*, while the results are presented in sections *6.3.3.1.1. Fuzzy overlay of post-mining characteristics* and *6.3.3.1.2. Fuzzy overlay of urban characteristics.* The integration of post-mining and urban landscape characteristics was undertaken in two steps for each landscape. First, the landscape characteristics identified from the literature were integrated and mapped. Second, the landscape characteristics identified by the local experts through the online survey were combined and mapped.

Fuzzy overlay analysis was conducted in two steps. First, each criterion under study was converted to fuzzy membership values using fuzzy membership functions (Table 3). Standard membership functions can assign high membership to low, high, or values centred on an ideal value (Rosenbery, 2019). These functions, therefore, favour desired criteria in a dataset using a continuous scale rather than creating discrete binary categories. Using a graduated scale prevents the creation of unnecessary or inaccurate binary relationships in the data. A value of ‘0’ is non-membership, while ‘1’ signifies full membership status of a specific criterion, and the infinite values in between have likely or partial membership. Therefore, most data points fall between 0 and 1 (Mitchell, 2012). The linear fuzzy membership function is applied in this study as it enables the inclusion or exclusion of minimum and maximum values in a data set. This was especially useful as the data had been reclassified, and the mapping of post-mining and urban landscape characteristics favoured low or high values in some criteria. The linear function enabled the inclusion or exclusion of low or high values. Thereafter, the collapsed characteristics of post-mining and urban landscape characteristics were used to inform the combination of the identified data into the required criteria presented in Table 10[38].

5.5.2.1.1. Fuzzy overlay of post-mining landscape characteristics

Table 11 presents the criteria and membership assigned for each characteristic of post-mining landscapes based on the characteristics identified from the literature. Before creating fuzzy membership layers for each criterion, each had been reclassified and assigned scores ranging from 9 to 1, based on the AHP method, to make assigning membership easier. Once the fuzzy membership was applied per the specifications in Table 10 and 11, maps of each membership layer were created using a uniform symbology, enabling comparability.

Table 11: Membership conditions of post-mining landscape characteristics from literature.

CRITERION	MEMBERSHIP	FUNCTION
Economic decline and lack of economic diversification:		
Business count per km^2	Favour low values	Linear
Industry count per km^2	Favour low values	Linear
Active mines per km^2	Favour low values	Linear
Unemployment per km^2	Favour high values	Linear
Abandoned mines per km^2	Favour high values	Linear
Population decline and collapse:		
Population per km^2	Favour low values	Linear
Integrative rehabilitation and management:		
Post-mining land uses per km^2	Favour high values	Linear
Development within mine dumps buffer per km^2	Favour high values	Linear
Development within slimes buffer per km^2	Favour high values	Linear
Social impact:		
Proportion of population within proximity of mine dumps per km^2	Favour high values	Linear
Proportion of population within proximity of slimes per km^2	Favour high values	Linear
Unemployment per km^2	Favour high values	Linear
Inaccessibility:		
Road accessibility (not within 500m) per km^2	Favour low values	Linear
Railway accessibility (not within 1000m) per km^2	Favour low values	Linear
Abandoned mines and infrastructure:		
Abandoned mines per km^2	Favour high values	Linear
Mining-related buildings per km^2 (1990)	Favour high values	Linear
Mining-related buildings per km^2 (2020)	Favour high values	Linear

[38] Most of the data were used to create complex criterion that could not be represented by only one spatial layer. However, not all criteria needed to be represented by multiple spatial layers and could be represented by individual spatial layers. For example, on the one hand, the population data was included in the combination used to create the social impact criteria, where population data was added to represent the social injustice associated with staying in close proximity to mine waste – as this is a possibility. On the other hand, the population data (low population) was used to create a standalone criterion as post-mining landscapes are said to have low population densities.

Mining-related land transformation:		
Historical mining-related land cover/use (1990) per km^2	Favour high values	Linear
Present-day mining-related land cover/use (2020) per km^2	Favour high values	Linear
Natural resource use and degradation:		
Low NDVI values per km^2	Favour low values	Linear
Mine residue areas per km^2	Favour high values	Linear
Mines to barren/eroded per km^2	Favour high values	Linear

After assigning different membership functions for each criterion, the fuzzy membership layers were combined to create a fuzzy overlay result favouring abandoned mines, mining leases and proclaimed land, mining-related land use or transformation, rehabilitation, and mine residue areas. By contrast, this overlay disfavours areas with businesses, industries, population, and access to roads and railways per km^2. Table 12 below presents, in no particular order, the different fuzzy overlay approaches applied to the criteria[39]. The fuzzy membership of each was created using the linear function for minimum values. The low count of businesses and industries per km^2, active mines and high unemployment per km^2 create a fuzzy membership raster for economic development and decline using the fuzzy operator OR. Using the fuzzy operator AND, a fuzzy overlay raster of mining-related land transformation was created by combining the mining-related classes from the 1990 and 2020 land cover/use data. All the mining classes in 1990 had changed to another use in 2020 and were combined using a linear function to generate an overlay for rehabilitation using the fuzzy operator OR. The proximity of a proportion of the population to slimes and mine dumps and a high count of unemployment per km^2 was used to generate a proxy for social impacts using the fuzzy operator AND. Mine buildings and abandoned mines per km^2 were combined to create a proxy for abandoned mine infrastructure using the fuzzy operator AND. The combination of the distance from roads and railways per km^2 generates an inaccessibility fuzzy overlay raster using the fuzzy operator OR. The natural resource use and degradation fuzzy overlay was generated by combining areas with low NDVI values, mine residue areas, and areas previously occupied by mining-related land uses that had been replaced by barren or eroded land using the fuzzy operator OR. The final overlay was created by combining all criteria using the Fuzzy operator OR.

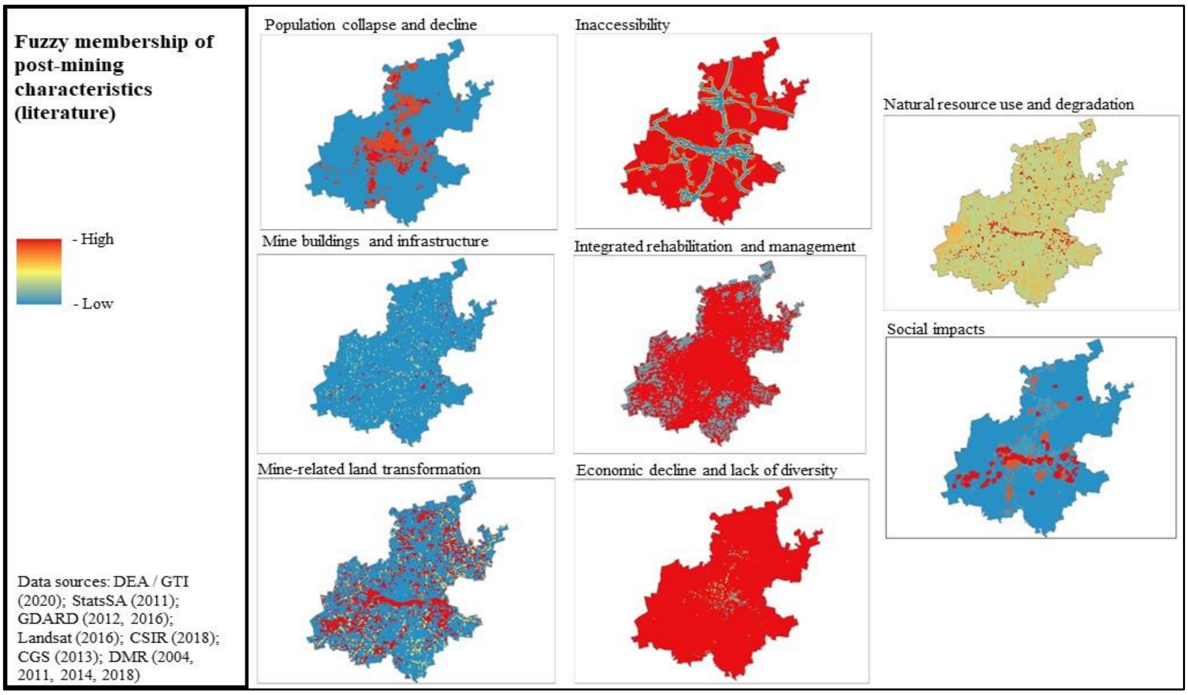
Table 12: Membership approaches used to generate fuzzy overlay of post-mining landscape characteristics from literature.

CHARACTERISTIC	APPROACH	REASON
Economic decline and lack of economic diversification:	OR	Allows the combination of industries, businesses, active mines, high unemployment and abandoned mines.
Low business count per km^2		
Low industry count per km^2		
Active mines per km^2		
High unemployment per km^2		
Abandoned mines per km^2		

[39]These tables were created prior to the elimination of any factors and with the intention of providing weight to the analysis using a combination of logic operators as in Qiu et al. (2014).

Population decline and collapse: Low population per km^2		No combination required
Integrative rehabilitation and management: Post-mining land uses per km^2 Development within mine dumps buffer per km^2 Development within slimes buffer per km^2	OR	Allows the combination of the areal extent of post-mining land uses and development within dumps and slimes buffers.
Social impact: Proportion of population within proximity of mine dumps per km^2 Proportion of population within proximity of slimes per km^2 High unemployment per km^2	OR	Allows the combination of the areal extent of the population proportion per km^2 within proximity of mine dumps and slimes, high unemployment and population per km^2.
Inaccessibility: Low road accessibility (not within 500m) per km^2 Low railway accessibility (not within 1000m) per km^2	AND	'AND' is limiting, whereas 'OR' and 'GAMMA' overcompensate. Also, post-mining landscapes have limited accessibility, 'AND' is the preferred operator to use as it returns the minimum value of the sets the cell location belongs to.
Abandoned mines and infrastructure: Abandoned mines per km^2 Mine-related buildings per km^2 (1990) Mine-related buildings per km^2 (2020)	OR	Allows the combination of the areal extent of both the abandoned mines and the mine buildings
Mining-related land transformation: Historical mining-related land cover/use (1990) per km^2 Present-day mining-related land cover/use (2020) per km^2	AND	Allows the combination of all mining-related cover/use, even land rehabilitated and replaced by other non-mining uses.
Natural resource use and degradation: Low NDVI values per km^2 Mine residue areas per km^2 Mines to barren/eroded per km^2	OR	Allows the combination of the areal extent of low NDVI values, mine waste and residue areas and land degraded to a barren or eroded state.

A composite of the criteria listed in Table 12 is presented in Map 8. The scale used to map the resultant overlay values ranges from 0 to 1, with 1 being the highest fuzzy overlay and, therefore, the favourability score. A score of 0 represents the lowest score, and the area in question has limited post-mining landscape characteristics. The maps use a graduated colour ramp, indicating the highest fuzzy membership values in orange and red. In contrast, lower fuzzy membership values are indicated in shades of blue to yellow. The final overlay, combining all the fuzzy membership rasters presented in Map 8, was created to present a map of the post-mining landscape characteristics identified in the literature. The results are presented in *6.3.3.1.1. Fuzzy overlay of post-mining characteristics*. The ArcGIS model of these processes is presented in Appendix 7.



Map 8: Fuzzy membership and overlay used to create the final overlay of the post-mining landscape using characteristics from literature (refer to the enlarged map in Appendix 8).

Following the assignment of the fuzzy memberships and the combination of the post-mining landscape characteristics identified from the literature, the same process was followed using the post-mining landscape characteristics identified from local experts. By contrast, this overlay favours areas with businesses, industries, population, and access to roads and railways per km^2 and a linear fuzzy membership function was used for each of them, favouring the maximum values of each. The low count of businesses and industries per km^2, active mines, high business count per km^2 and high industry count per km^2 create a fuzzy overlay raster for economic development and decline using the fuzzy operator OR. Using the fuzzy operator AND, the mining-related classes from the 1990 and 2020 land cover/use layers generated a fuzzy overlay of mining-related land transformation per km^2. The two informality classes from 1990 and 2020 were combined to create an informality fuzzy overlay using the fuzzy operator AND. The proximity of a proportion of the population to slimes and mine dumps, a high count of unemployment per km^2 and informality were used to generate an overlay of social impacts using the fuzzy operator OR. Mine buildings and abandoned mines were combined to generate a fuzzy overlay using the Fuzzy operator OR for abandoned mine infrastructure. The fuzzy layer of natural resource use and degradation was generated by combining areas with low NDVI values, mine residue areas, and areas previously occupied by mining-related land uses replaced by barren or eroded land and waste (per km^2) using the fuzzy operator OR. The fuzzy operator AND combined the urban-related classes from

1990 and 2020 land cover/use data per km^2. The combination of roads and railway access generates a high access fuzzy membership raster using the fuzzy operator OR.

The tables demonstrating the assignment of fuzzy membership to post-mining landscape characteristics from local experts are presented in Appendix 9, while a table demonstrating the resultant fuzzy layer combination approach is presented in Appendix 10, and a fuzzy membership map of post-mining landscape characteristics is presented in Appendix 11[40].

5.5.2.1.2. Fuzzy overlay of urban landscape characteristics

Table 13 presents the criteria and membership assigned for each characteristic of urban landscapes based on the characteristics identified from the literature. Before creating fuzzy membership layers for each criterion, each had been reclassified and assigned scores ranging from 9 to 1, based on the AHP method, to make assigning membership easier. Once the fuzzy membership was applied per the specifications in Table 10 and 13, maps of each membership layer were created using a uniform symbology, enabling comparability.

Table 13: Membership conditions of urban landscape characteristics from literature.

CRITERION	MEMBERSHIP	FUNCTION
Economic development and diversity:		
Business count per km^2	Favour high values	Linear
Industry count per km^2	Favour high values	Linear
Unemployment rate per km^2	Favour low values	Linear
Mobility and accessibility:		
Railway accessibility (most favourable - within 1000m)	Favour high values	Linear
Road accessibility (most favourable - within 500m)	Favour high values	Linear
Population density:		
High population count per km^2	Favour high values	Linear
Inequality:		
Unemployment rate per km^2	Favour high values	Linear
Population density per km^2	Favour high values	Linear
Urban-related land transformation:		
Historical urban-related land cover/use (1990) per km^2	Favour high values	Linear
Present-day urban-related land cover/use (1990) per km^2	Favour high values	Linear
Urban-related built infrastructure:		
Urban-related built-up areas per km^2 (1990)	Favour high values	Linear
Urban-related built-up areas per km^2 (2020)	Favour high values	Linear
Informality:		
Informal dwellings and residential areas per km^2 (1990) per km^2	Favour high values	Linear
Informal dwellings and residential areas per km^2 (2020) per km^2	Favour high values	Linear
Natural resource use and degradation:		
NDVI values per km^2	Favour low values	Linear

[40] The ArcGIS model of these processes is presented in Appendix 12.

Urban to barren/eroded per km^2	Favour high values	Linear
Waste per km^2	Favour high values	Linear

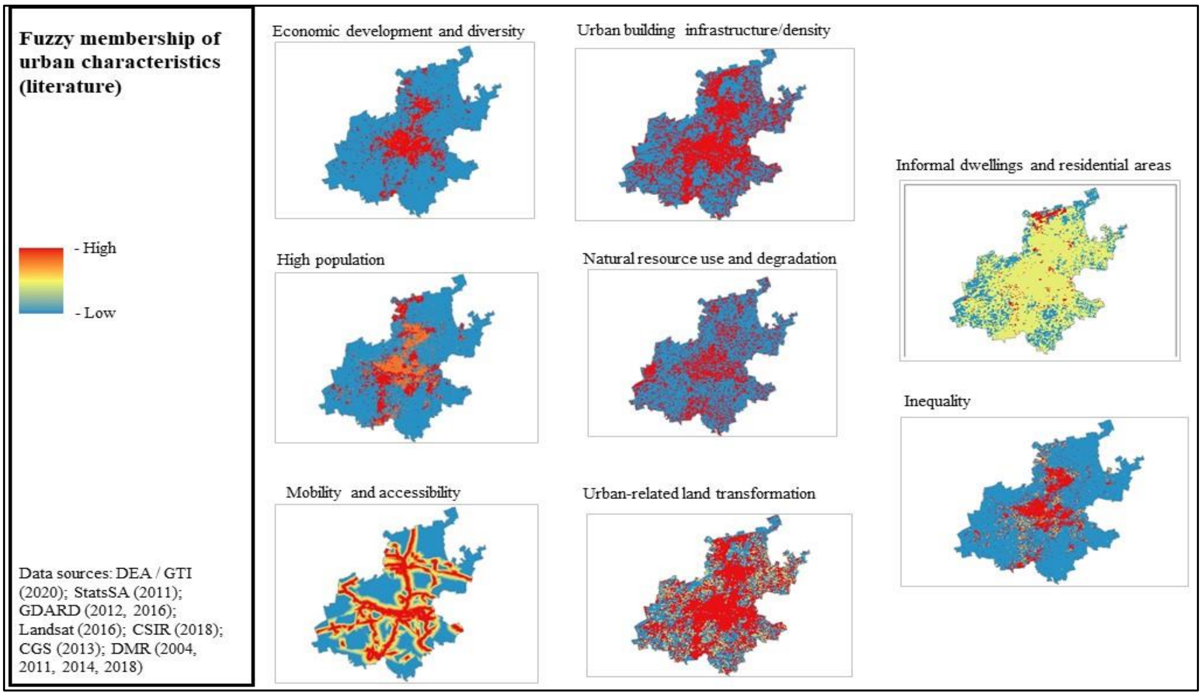
The fuzzy membership layers are based on the groupings in Table 13. The fuzzy membership layers were combined with the ultimate goal of a fuzzy overlay result favouring all urban-related land transformation and use, urban-related natural resource use and degradation, areas with high businesses, industries, unemployment and population per km^2 and high access to roads and railways. Table 14 below presents the different fuzzy overlay approaches applied to the criteria. For the mapping of urban landscape characteristics identified from the literature, the fuzzy overlay favouring all urban-related land transformation and use, urban-related natural resource use and degradation, areas with high businesses, industries, unemployment and population and high access to roads and railways per km^2, of which a linear fuzzy membership function was used to generate individual fuzzy membership for each. Using the operator OR, high businesses, commercial land use class, and industries per km^2 create a fuzzy overlay of economic development and diversity. The urban-related classes from the 1990 and 2020 land cover/use data were combined to generate an overlay of urban-related land transformation and use per km^2 using the operator AND. Using the operator OR, a waste overlay was created by combining general waste, sewage and hazardous waste per km^2. Using the operator OR, the natural resource use and degradation fuzzy overlay was generated by combining areas with low NDVI values and waste per km^2. The combination of informal dwellings from 1990 to 2020 (per km^2) generates an informal fuzzy overlay using the operator AND. Another combination of high population, unemployment, and informality generates a fuzzy overlay of inequality using the operator OR.

Table 14: Membership approaches used to generate fuzzy overlay of urban landscape characteristics from literature.

CHARACTERISTIC	APPROACH	REASON
Economic opportunities and diversity:	OR	Overcompensates and allows the combination of industries, businesses and low unemployment.
High business count per km^2		
High industry count per km^2		
Low unemployment rate per km^2		
Mobility and accessibility:	OR	Overcompensates access as urban areas are supposedly encouraging mobility and accessibility.
High railway accessibility (most favourable - within 1000m) per km^2		
High road accessibility (most favourable - within 500m) per km^2		
Population density:		No combination required
High population count per km^2		
Inequality:	OR	Allows the combination of the unemployment rate and high population counts.
High unemployment rate per km^2		
High population density per km^2		
Urban-related land transformation:	AND	Allows the combination of all urban-related cover/use.
Historical urban-related land cover/use (1990) per km^2		
Present-day urban-related land cover/use (1990) per km^2		
Urban-related built infrastructure:		Allows the combination of all urban-

Urban-related built-up areas per km^2 (1990)	AND	related built infrastructure.
Urban-related built-up areas per km^2 (2020)		
Informality:	AND	Allows the combination of informal dwellings from 1990 and 2020.
Informal dwellings and residential areas(1990) per km^2		
Informal dwellings and residential areas (2020) per km^2		
Urban-related natural resource use and degradation:	OR	Allows the combination of low NDVI values and land that urban activities have degraded
Low NDVI values per km^2		
Urban to barren/eroded per km^2		
Waste per km^2		

Map 9 below is a composite of the different combinations of fuzzy membership, as presented in Table 14. The resultant overlay map used a scale and colours identical to the above-mentioned. The ArcGIS model of these processes is presented in Appendix 13.



Map 9: Fuzzy membership and overlay used to create the final overlay of the urban landscape characteristics from literature (refer to the enlarged map in Appendix 14).

Following the assignment of the fuzzy memberships and combination of the urban landscape characteristics identified from the literature, the same process was followed using the urban landscape characteristics identified from local experts. The fuzzy overlay favoured all urban-related land transformation and use, urban-related natural resource use and degradation, areas with high businesses, industries, unemployment, high population and high access to roads and railways per km^2, also including some post-mining characteristics**.** Fuzzy membership layers were created using the linear function favouring high values; this was done so that each of the resultant fuzzy membership layers highlighted the cells with the highest values to demonstrate the high rate of economic development characterising post-mining landscapes in this context. The fuzzy operator OR was used to overlay unemployment, businesses and industries per km^2 to create a fuzzy overlay for economic development and diversity. The urban-related classes from the 1990 and 2020 land cover/use data were combined using the operator AND to generate an overlay of urban-related land transformation and use. The operator OR generated a waste overlay, combining general waste, sewage and hazardous waste per km^2. Using the operator OR, the natural resource use and degradation fuzzy overlay was generated by combining areas with low NDVI values and waste per km^2. A combination of informal dwellings from 1990 to 2020 (per km^2) was generated using the operator AND. Using the operator OR, another fuzzy overlay combines high population, unemployment, and informality. Using the operator OR, the combination of roads and railway access per km^2 generates an access overlay. The two informality classes from 1990 and 2020 were combined to create an informality fuzzy overlay. The proximity of a proportion of the population to slimes and mine dumps, a high count of unemployment per km^2 and informality were used to generate an overlay of social impacts using the operator OR. Mine buildings and abandoned mines were combined to generate a fuzzy overlay for abandoned mine infrastructure using the operator OR. The fuzzy overlay of natural resource use and degradation was generated by combining, using the operator OR, areas with low NDVI values, mine residue areas, and areas previously occupied by mining-related land uses replaced by barren or eroded land and waste (per km^2). The final overlay was generated using the operator OR, combining all the above-mentioned characteristics.

The tables demonstrating the assignment of fuzzy membership to urban landscape characteristics from local experts are presented in Appendix 15, while a table demonstrating the fuzzy membership layer combination approach is presented in Appendix 16, and a fuzzy membership map of urban landscape characteristics is presented in Appendix 17[41].

5.5.2.2. Weighted overlay analysis of post-mining and urban landscape characteristics

The second mapping technique investigated to demonstrate its capacity for integrating urban and post-mining characteristics is *Weighted Overlay, discussed in section 4.4.2. Weighted overlay*. Weighted overlay is an approach that reclassifies the values of a series of input rasters to a specified scale, weights the importance of each, and generates and performs a multi-criteria analysis of all weighted layers that prioritises certain areas. Weighted overlay analysis was used in this study because of its ability to handle conflicting criteria, such as the characteristics used to characterise post-mining and urban landscapes.

[41] The ArcGIS model of these processes is presented in Appendix 18.

This approach differs from fuzzy overlay, which defines the possibility of membership to sets, making it more flexible, while weighted overlay uses a relative preference scale.

The weighted overlay approach applied to the post-mining and urban landscape characteristics of the Gauteng landscape is presented below in sections *5.5.2.2.1. Weighted overlay of post-mining characteristics* and *5.5.2.2.2.Weighted overlay of urban characteristics*. In comparison, the results are presented in sections *6.3.3.2.1. Weighted overlay of post-mining characteristics* and *6.3.3.2.2. Weighted overlay of urban characteristics.*

The weighted overlay analysis was conducted on ArcMap 10.3, and similar to the integration and mapping of post-mining and urban landscape characteristics conducted using fuzzy overlay analysis, the weighted overlay analysis was undertaken in two steps for each of the landscapes. First, the landscape characteristics identified from the literature were integrated and mapped. Second, the landscape characteristics identified from the local experts through the online survey were integrated and mapped. While weighted overlay depends on the weighting of the input criteria, equal weighting was applied where possible. In cases where there was an uneven number of variables, equal weighting randomly assigned a higher weighting to any of the layers – this was changed so that more weighting was given to the layers most appropriate to the variable, for example, post-mining land uses were given a weight of 34 and the other two comprising the combination, values of 33.

5.5.2.2.1. Weighted overlay of post-mining landscape characteristics

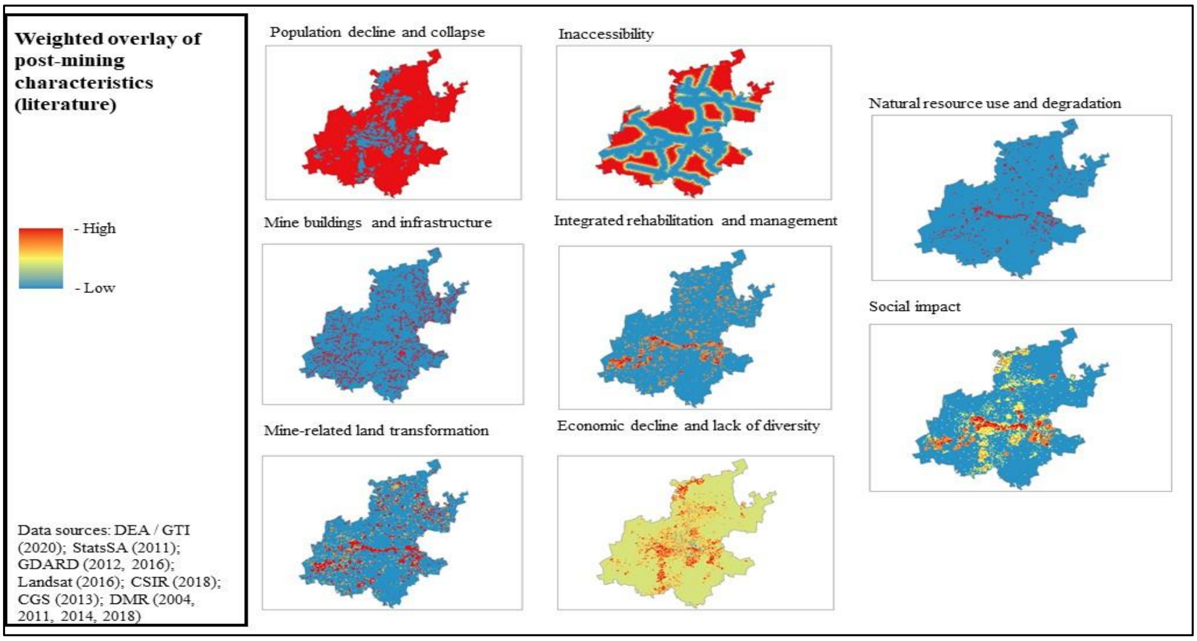
Table 15 presents the variables for the weighted overlay for each of the characteristic criteria of post-mining landscapes based on the characteristics identified from the literature. Similar to the fuzzy overlay analysis, each variable had to be reclassified and assigned scores ranging from 9 to 1 to make the weighting of the variables easier. As in the fuzzy overlay analysis, some data (column two in the table) were combined to generate the required weighted overlay variables. Combinations of variables are presented in the second column, and the influence weight of the variables is indicated in the third column. The weighting influence applied in the generation of the final weighted overlay is indicated in the last column.

Table 15: Weighted overlay criteria used to map post-mining landscape characteristics from literature.

VARIABLE	WEIGHTED OVERLAY CRITERIA	INFLUENCE WEIGHTING %	OVERALL VARIABLE WEIGHTING	INFLUENCE WEIGHT %
Natural resource use and degradation	NDVI low values per km^2	33	100	11
	Mines to barren/eroded per km^2	33		
	Mine waste and residue per km^2	34		
Integrated rehabilitation and management	Post-mining land use per km^2	34	100	11
	Development and use in slimes per km^2	33		
	Development and use in dumps per km^2	33		

Mining-related land transformation	Mining-related land use per km^2 (1990)	50	100	13
	Mining-related land use per km^2 (2020)	50		
Economic decline and lack of economic diversity	Low business count per km^2	20	100	13
	Low industry count per km^2	20		
	Abandoned mines per km^2	20		
	Active mines per km^2	20		
	High unemployment per km^2	20		
Social impact	Population near slimes per km^2	33	100	13
	Population near dumps per km^2	33		
	High unemployment per km^2	34		
Population decline and collapse	Low population per km^2	100	100	12
Inaccessibility	Low road accessibility (not within 500m) per km^2	50	100	13
	Low railway access (not within 1000m) per km^{25}	50		
Abandoned mine infrastructure and buildings	Mine-related buildings per km^2 (1990)	50	100	13
	Mine-related buildings per km^2 (2020)	50		
				100%

The combinations of the post-mining landscape characteristics based on literature using a weighted overlay are presented in Map 10. Each of the mapped variables is mapped using a graduated scale for comparability. The highest weighted overlay values are indicated in orange and red. In contrast, lower weighted overlay values are indicated in shades of blue to yellow. The ArcGIS model of these processes is presented in Appendix 19.



Map 10: Weighted overlays of post-mining characteristics from literature (refer to the enlarged map in Appendix 20).

Once the weighted overlay analysis had been applied to the post-mining landscape characteristics identified from the literature, the same process was followed using the post-mining landscape characteristics identified from local experts. The tables and map demonstrating the weighting of the variables of post-mining landscape characteristics from local experts are presented in Appendix 21 and 22. At the same time, the resultant weighted overlay from the combination of weighted overlay layers of post-mining landscape characteristics identified from local experts is also presented in section *6.3.3.2.1. Weighted overlay of post-mining characteristics*[42].

5.5.2.2.2. Weighted overlay of urban landscape characteristics

Table 16 presents the input variables for the weighted overlay of urban landscape characteristics. Some of the data were combined to generate the required weighted variables. Table 16 presents the variables for the weighted overlay for each characteristic criterion of urban landscapes based on the characteristics identified from the literature. Similar to the weighted overlay analysis of post-mining landscape characteristics, each variable had to be reclassified and assigned scores ranging from 9 to 1. Some of the variables had to be combined to create some of the variables, as in the fuzzy overlay analysis. Combinations of variables are presented in the second column, and the influence weight of the variables is indicated in the third column. The default overall weight of 10% was applied for each variable for the final weighted overlay result.

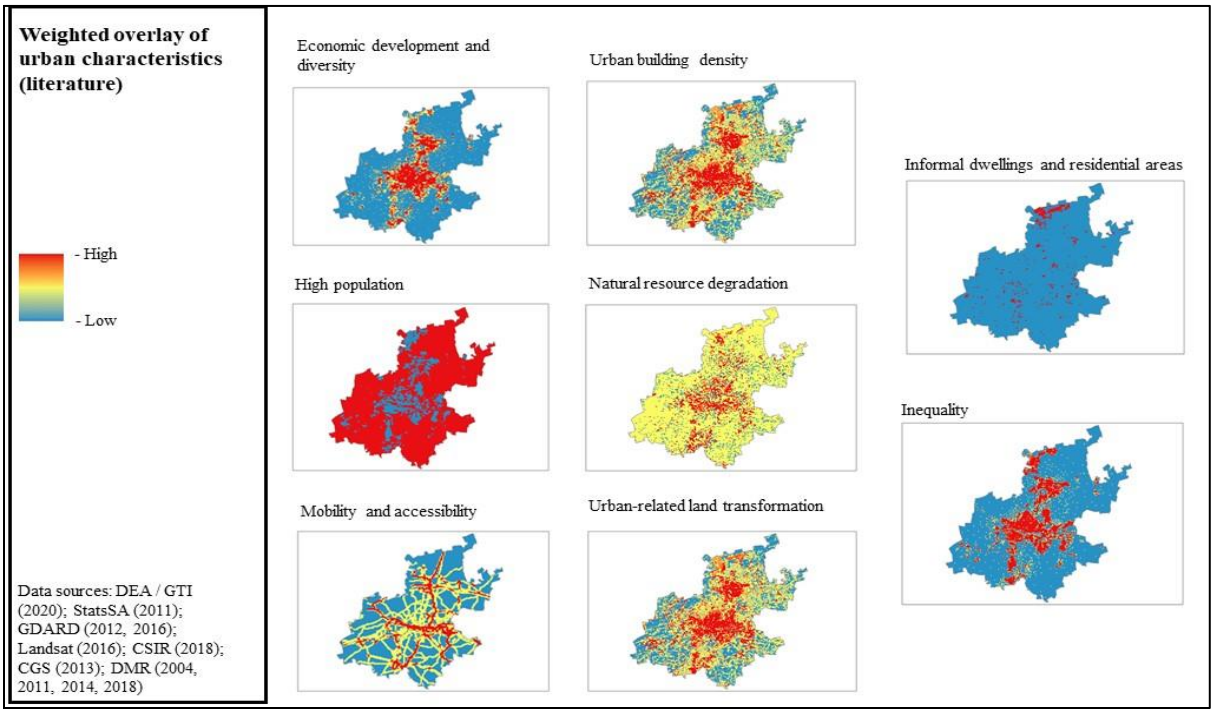
Table 16: Weighted overlay criteria used to map urban landscape characteristics from literature.

WEIGHTED OVERLAY VARIABLES	WEIGHTED OVERLAY CRITERIA	INFLUENCE WEIGHTING %	WEIGHTED OVERLAY	OVERALL INFLUENCE WEIGHTING %
Natural resource use and degradation	NDVI low values per km^2	33	100	12
	Urban to barren/eroded per km^2	33		
	Waste per km^2	34		
Urban-related land transformation	Urban land classes per km^2 (1990)	50	100	12
	Urban land classes per km^2 (2020)	50		
Economic development	High business per km^2	34	100	13
	High industry per km^2	33		
	Low unemployment per km^2	33		
Inequality	Low unemployment per km^2	50	100	12
	High population count per km^2	50		
High population density	High population per km^2	100	100	12
Accessibility	Roads (within 500m)	50	100	12
	Railway (within 1000m)	50		
	Urban-related buildings per km^2 (1990)	50	100	

[42] The ArcGIS model of these processes is presented in Appendix 23.

Urban-related built infrastructure	Urban-related buildings per km2 (2020)	50		13
Informality	Informality per km^2 (1990)	50		
	Informality per km^2 (2020)	50	100	12
				100

A composite of the urban landscape characteristics variables listed in Table 16 is presented in Map 11. The maps use a graduated colour ramp, with the highest weighted overlay values indicated in orange and red. The ArcGIS model of these processes is presented in Appendix 24.



Map 11: Weighted overlays used to create the final overlay of the urban landscape characteristics from literature (refer to the enlarged map in Appendix 25).

Once the weighted overlay analysis had been applied to the urban landscape characteristics identified from the literature, the same process was followed using the urban landscape characteristics identified from local experts. The tables and map demonstrating the weighting of the variables of urban landscape characteristics from local experts are presented in Appendix 26 and 27. At the same time, the resultant weighted overlay from the combination of weighted overlay layers of urban landscape characteristics identified from local experts is also presented in section *6.3.3.2.2. Weighted overlay of urban characteristics*[43].

[43] The ArcGIS model of these processes is presented in Appendix 28.

5.5.2.3. Random forest classification of post-mining and urban landscape characteristics

Random Forest classification is the third mapping technique explored for mapping the integration of urban and post-mining landscape characteristics in Gauteng. Random forest is a technique used in modelling predictions and behaviour analysis built on decision trees. The relevant task in this research was the application of random forest classification in integrating several post-mining and urban landscape characteristics. Random forest classification was applied to the data as a comparative method to the other two mapping methods using overlay techniques. Random forest in this study was used to predict an area's characteristics based on similar landscape characteristics.

Data processing entailed first the creation of training data, followed by the test data. The training data was created in Excel and comprised four hundred (400) data rows for each landscape to be classified. Once the Excel sheet had been created, the attribute information of 400 (of the 18851 grid cells comprising the fishnet grid) of each variable was extracted from the Attribute table - using *Copy select.* The variables' attribute information values[44] associated with each landscape were copied onto the same Excel sheet. After that, the cumulative value of urban or post-mining characteristics was calculated by adding all the reclassification values of all variables within a grid cell and then dividing by the total (in this case, each predictor variable range from 1 to 9) and multiplied by 100 to get a percentage score. Grid cells were classified as ‘post-mining’ or ‘urban’ if more than 40% of the respective characteristics comprised the grid cell area for the characterisations directly adopted from the literature[45]. The random forest classifications of the post-mining and urban characteristics informed by expert input were less conservative, as the grid cells with a cumulative percentage of 30% were considered here. In some grid cells, only a few characteristics considered post-mining or urban were present; for example, some grid cells with mine waste and close to roads, but away from businesses and high population densities[46]. However, it was important to demonstrate the co-existence of these two landscapes for this study, hence the 30% threshold. The presence of either urban or post-mining characteristics was indicated as “1”, or

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[44] Similar to previous models, the model was generated based on a grid and used the reclassified data. More information on how the data was reclassified is presented in Table 10 in section *6.3.3.2. Reclassification and ranking of data*.

[45] This was adopted to accommodate those cells where the characteristics of urban landscapes such as economic development and diversity, high population, accessibility, informality and waste were present.

[46] These grid cells contained some mining characteristics in the form of mine waste and were included. In addition, local experts identified mining as one of the urban characteristics; however, some areas only had mining characteristics. These areas would have been excluded from mapping and post-mining or urban. Therefore, a threshold of 30% was considered in these areas, and this change was introduced so the additional predictor variables could be picked up in the model.

the absence of urban or post-mining characteristics was indicated as “0”. Once all of the steps outlined had been completed, the Excel spreadsheets were saved as training data for each landscape under study.

A test data set was created by creating two new Excel spreadsheet files, each with 18851 rows (the same as the fishnet grid). The variable values for all the characteristics associated with post-mining and urban landscapes were extracted onto the two Excel files created in the previous step for the test data and saved.

Random forest classification was undertaken using R (a programming language for statistical computing and graphics), version 4.2.2 and RStudio (an integrated development environment (IDE) for R). Before the data analysis, the necessary libraries were loaded, such as “*randomForest*” and “*caret*”, which provided the required tools. Thereafter, a random forest classifier was created, specifying the locations of the training data (predictor variables) and variables. The number of trees and features considered at each tree node split were also specified to train the random forest classifier. Once the model had been trained, predictions were made on the test data using the training data (predictor variables). This process was followed twice to make predictions for post-mining and urban landscape characteristics, using both the literature and expert-derived landscape characteristics. Both models' results were exported into separate Excel spreadsheet files for each landscape.

Data manipulation was conducted in Excel, where the abovementioned thresholds for predicting post-mining and urban landscape characteristics were applied and then visualised on ArcMap 10.3. The Excel spreadsheets presenting all these workings are in Appendix (29-32).

The analysis of urban and post-mining landscape characteristics using the Random forest classification method is outlined in sections *5.5.2.3.1. Random forest classification of post-mining characteristics* and *5.5.2.3.2. Random forest classification of urban characteristics*. The results from the random forest classification of post-mining and urban landscape characteristics are outlined in sections *6.3.3.3.1. Random forest classification of post-mining landscape characteristics* and *6.3.3.3.2. Random forest classification of urban landscape characteristics.*

5.5.2.3.1. Random forest classification of post-mining characteristics

The predictor variables considered for the modelling of post-mining characteristics, as identified from the literature using a random classification, are listed in Table 17. On the other hand, the predictor variables considered for modelling post-mining landscape characteristics, as identified by local experts, are presented in Appendix 29 and 30. Grid cells were classified as ‘post-mining’ if more than 50% of the area of each grid cell had post-mining characteristics. The results from the random forest classification of post-mining landscapes are presented in section *6.3.3.3.1. Random forest classification of post-mining landscape characteristics.*

Table 17: Predictor variables used for the random forest classification of post-mining landscape characteristics.

CATEGORY	PREDICTOR VARIABLE	TYPE
Natural resource use and degradation	NDVI low values per km^2	Binary
	Mines to barren/eroded per km^2	Binary
	Mine waste and residue per km^2	Binary
Integrative rehabilitation and management	Post-mining land uses per km^2	Binary
	Development and use in slimes per km^2	Binary
	Development and use in slimes per km^2	Binary
Mining-related land transformation	Mining-related land use (1990) per km^2	Binary
	Mining-related land use (2020) per km^2	Binary
Economic decline and lack of economic diversity	Low business per km^2	Binary
	Low industry per km^2	Binary
	Abandoned mines per km^2	Binary
	Active mines per km^2	Binary
	High unemployment per km^2	Binary
Social impact	Population near slimes per km^2	Binary
	Population near dumps per km^2	Binary
	High unemployment per km^2	Binary
Low population	Low population per km^2	Binary
Inaccessibility	Roads per km^2	Binary
	Railway per km^2	Binary
Abandoned mine infrastructure and buildings	Mine-related buildings per km^2 (1990)	Binary
	Mine-related buildings per km^2 (2020)	Binary

5.5.2.3.2. Random forest classification of urban characteristics

The predictor variables considered for modelling urban landscape characteristics, as identified from the literature using a random classification, are listed in Table 18. In contrast, the predictor variables of urban landscape characteristics identified by local experts are presented in Appendix 31 and 32. In both, the cumulative value of urban landscape characteristics per grid was added, divided by the total and multiplied by 100 to get a percentage score. Grid cells were classified as 'urban' if more than 50% of the area of each grid cell had urban landscape characteristics. The results from the random forest classification of post-mining landscapes are presented in section *6.3.3.3.2. Random forest classification of urban landscape characteristics.*

Table 18: Predictor variables used for the random classification of urban landscape characteristics.

CATEGORY	PREDICTOR VARIABLE	TYPE
Natural resource use and degradation	Low NDVI values per km^2	Binary
	Urban to barren/eroded per km^2	Binary
	Waste per km^2	Binary
Urban-related land transformation	Urban-related land use (1990) per km^2	Binary
	Urban-related land use (2020) per km^2	Binary
Economic development and diversity	High business per km^2	Binary
	High industry per km^2	Binary
	Low unemployment per km^2	Binary
Inequality	Low unemployment per km^2	Binary
	High population count per km^2	Binary
High population density	High population per km^2	Binary
Accessibility	Roads (within 500m) per km^2	Binary
	Railway (within 1000m) per km^2	Binary
Urban-related built infrastructure	Urban-related buildings and infrastructure per km^2 (1990)	Binary
	Urban-related buildings and infrastructure per km^2 (2020)	Binary
Informality	Informal land use (1990) per km^2	Binary
	Informal land use (2020) per km^2	Binary

5.5.3. Testing and validation of the mapping of landscape characteristics

This research used four performance evaluation exercises to test the feasibility of integrating post-mining and urban landscape characteristics. First, this research evaluates the mapped results using a confusion error matrix, particularly user accuracy[47] and producer accuracy[48]. This research uses a hexagonal land use data set – 2021 GTI land cover - comprising mining-related and urban land use classes as the reference data. Mining and urban land use classes were extracted from the data using the '*Extract by attributes'* Spatial Analyst tool. The extracted data were used as the validation layers against all three models and were expected to have high accuracy across all three models as it is the closest to ground truth data. This particular data set was selected as a suitable validation layer for several reasons. It was not used in any of the prior mappings, it had relevant land use classes to the phenomenon studied in this research, it was a recently created data set, it was in an easily accessible format, it was accessible, and it had a high resolution of 400m x 400m. The accuracy evaluation of the data entailed the creation of 50 reference points[49] from the hexagonal mining and urban land use data, which was done using the

[47] Errors of commission, which typically occur when a pixel is incorrectly included in a category being evaluated.
[48] Errors of omission, which occur when a pixel is left out of the category being evaluated.
[49] 25 of the points were created using the extracted mining land use class, while the other 25 were created using a shapefile of Gauteng as the reference. The same was done for the urban land use class.

'*Create random points'* Spatial analyst tool. The '*Extract values to points'* tool in Spatial Analyst was used to extract the pixel values at each point. Once this was done, a frequency was used to isolate the frequency values for the resultant maps and reference points. This was conducted using the '*Frequency*' tool in 'Analysis Tools. The frequency was sorted by running a pivot (conducted using '*Pivot Table'* in Data Management Tools), and the data was exported to Excel using '*Table to Excel'* in Conversion Tools. Once in Excel, the following calculations were made in addition to those mentioned above:

a) Total reference points = sum of all reference points for each land use class

b) Total classified points = sum of pixels classified for that land use class

c) Total correct reference points = sum of pixel values correctly matched divided by the reference points

d) Total "true" reference points = sum of the total number of pixels provided as reference points

e) Percent Accuracy = [total correct reference points / total "true reference points] multiplied by 100

Second, two intentional point sample sets were created from the reference data using the '*Feature to point*" Conversion tool, one for mining land use and another for urban land use, each with 20 points. Additionally, 20 random points were created using the "*Create random points*" tool, which was also used to cross-evaluate the data. Third, the areal extent of post-mining and urban landscape characteristics was evaluated using the '*Extract by Attribute'* Spatial analyst tool to extract and calculate areas of post-mining and urbanisation. The proportion of model values that meet the following ranges: 0 – 25%, 26 - 50%, 50 - 75% and 76 - 100% of the highest possible value for each mapping result. Fourth, a change detection analysis[50] was conducted through image differencing against the results of each mapping technique to identify any discrepancies. Here, the difference between the maps derived from post-mining or urban landscape characteristics identified from the literature and those derived from local experts were calculated by finding the difference between each pixel in each image and generating an image based on the result. The image differencing was conducted using the 'Raster calculator' Spatial Analyst tool in ArcMap. These findings were compared across all maps, discussing the limitations of each mapping technique and limitations and merit more broadly.

The attribute information was edited to reflect the presence (1) and absence (0) of mining and urban land use.

[50] Change detection is the measure of thematic change information within a predefined period (Ernani and Gabriels, 2006). When change is assessed, four aspects are focused on, namely: detecting the change, the type of change, the distribution and quantifying the intensity of the change, assessing the trends before and after the changes (Macleod and Congalton, 1998). This study applies the post-classification change detection method, which is the most common technique based on classifications used in most studies, especially when data from different sensors are compared (Ahlqvist, 2008). This technique provides "*from-to*" information of different classes (Baolin and Qiming, 2009).

5.6. SUMMARY OF THE CHAPTER

This chapter has described and justified the design and methodologies employed to achieve the research objectives introduced in Chapter 1. A mixed methodology approach was carefully designed for the study, combining qualitative and quantitative methodologies and data. Several research techniques were adopted to accomplish the aim of the study, including document analysis, survey, case study and spatial analysis. The chapter also focussed on explaining the data collection, processing, preparation and analysis measures applied in the study. It also demonstrated the complexities of working with diverse data formats and their integration. The main focus of this chapter has been the comprehensive discussion of the development of the proposed framework, which entailed details on the criteria, analysis, and implementation, along with the discussion of the investigating steps undertaken to verify the findings.

CHAPTER SIX: ANALYSIS OF LANDSCAPE CHARACTERISTICS – A CASE STUDY OF GAUTENG

6.1. INTRODUCTION

This chapter presents the key characteristics identified in the characterisations of post-mining and urban landscapes. First, the chapter starts by presenting the findings from the literature, followed by findings from the survey conducted with local experts. This is followed by a presentation of the proposed conceptual and spatial frameworks based on the key landscape characteristics for integrating post-mining and urban landscape characteristics in Gauteng. The results culminating from the mapping results generated from the three multi-criteria mapping methods (fuzzy overlay, weighted overlay and random forest classification, applied to integrate and map post-mining and urban landscape characteristics) are presented. The mapping validation results are also presented and discussed in this chapter. Starting with a presentation of the confusion error matrix results, then the results from evaluating the areal coverage and concluding with the image differencing results.

6.2. IDENTIFICATION OF LANDSCAPE CHARACTERISTICS

Once the key characteristics in the literature related to post-mining and urban landscapes were identified, they collapsed and were categorised based on their similarities. Each of these critical concepts were defined to identify similarities in the definitions and applications of the concepts. Post the definition of the concepts, the landscape characteristics used to describe post-mining landscapes were collapsed into nine characteristics and the characteristics used to define urban landscapes were collapsed into eight. Altogether, the characteristics identified as being descriptive of both landscapes are artificial, assemblage, natural resource degradation, economic decline and collapse, sustainable development challenge, economic development and opportunities, social justice, culture and heritage, integrative rehabilitation and management, population decline, spatial and temporal. Complete tables of the identified descriptions of these two landscapes are attached, along with how they collapsed (refer to Appendix 33-37), including the definitions of the characteristics and the sources they were identified from.

6.2.1. Content analysis: Documentary analysis of conceptualisations of urban and post-mining characteristics

Figure 14 shows the nine themes from literature, archival material and policy documents coded from the characterisations of post-mining landscapes. Most descriptions (32%) of post-mining landscapes concern natural resource exploitation and pollution (such as mine dumps, acid mine drainage, tailings, slimes, etc.). This is followed by the impact of mining and its resultant waste on the surrounding communities and related conflict culminating from disproportionate costs and risks (17%). Fourteen per cent of post-mining landscape descriptions focused on the changes that come with and remain long after ceasing mining activities. Some 11% of descriptions of post-mining landscapes mainly relate to the economic development and decline that mining brings. These descriptions also sometimes mentioned the dependencies created by mining on the regional economy and society, especially where mining towns/communities failed to develop and diversify their economies beyond the mining activity. Eight per cent and 7% of descriptions relate to rehabilitation and post-mining landscapes being artificial, respectively. These characterisations of post-mining landscapes mainly describe post-mining landscapes as man-made and unnatural, to the point of being incompatible and needing rehabilitation, also highlighting abandoned mines and infrastructure. In comparison, only 2% of characterisations of post-mining landscapes describe post-mining landscapes as assemblages comprising a mix of characteristics and wide-ranging interrelatedness or in terms of the population changes that come with mining. While in the active stage of mining, mining attracts much labour. However, mining labour leaves due to mine downscaling and eventual closure of a mine, which leads to population changes in mining areas.

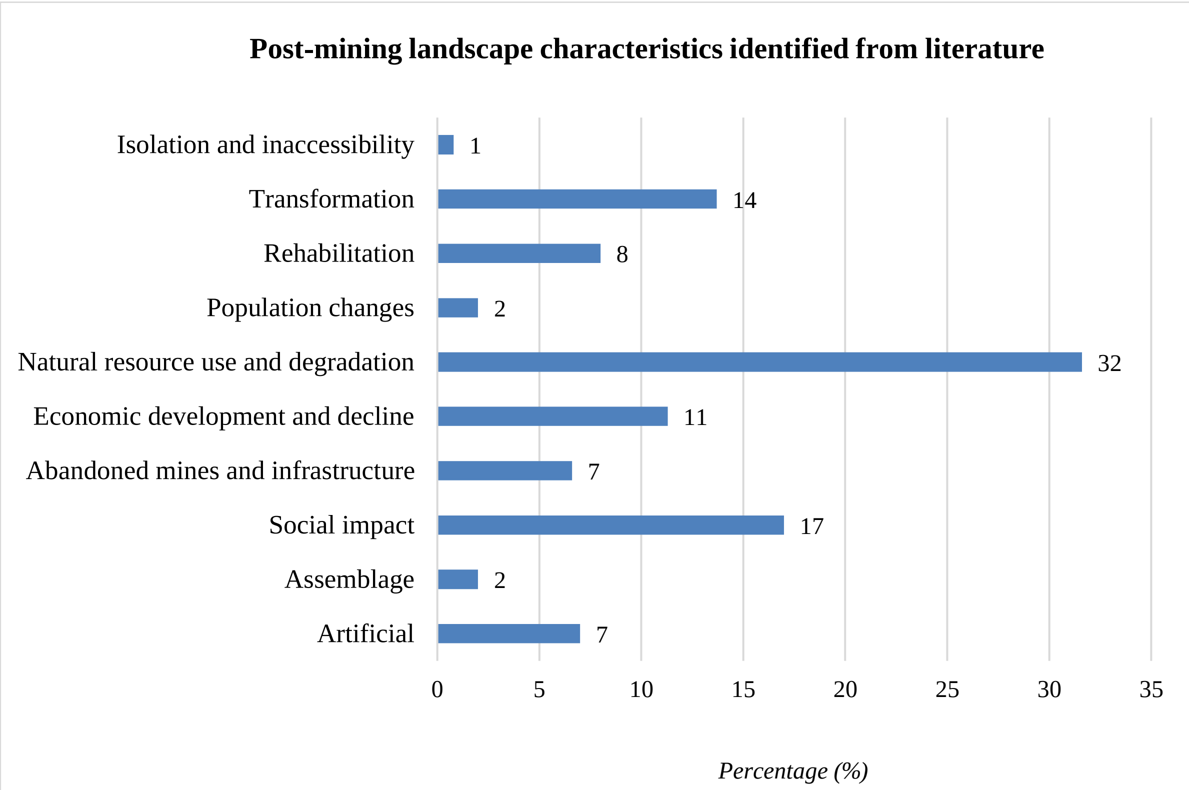

Figure 14: Post-mining landscape characteristics identified from the literature.

Figure 15 presents the emerging themes from keywords and characterisations of urban landscapes as found in literature and other documents. These themes were identified from the grouping of similar keywords and characteristics. The definition of keywords was collapsed into eight themes: Artificial, assemblage, natural resource use and degradation, economic development and opportunities, social impact and conflict, mobility and mutual accessibility, density and transformation. Most descriptions (20%) of the consulted literature on urban landscapes concern economic development and opportunities. This is followed by 19% of descriptions of the urban as an assemblage, consisting of a range of activities, such as diverse economic opportunities, cultures, etc. Seventeen per cent of the characteristics of urban landscapes are related to societal issues, such as inequality and political issues. Sixteen per cent of characteristics of urban landscapes focused on the landscape changes that come with urbanisation and the unprecedented expansion and sprawl of urban areas. Fourteen per cent of the identified characteristics of urban landscapes are related to the use of resources and the resultant pollution from urban processes. Seven per cent of keywords used in describing urban landscapes related to density, be it population density or building density. Only 3% of keywords related to urban landscapes being artificial and man-made and the accessibility of a range of services.

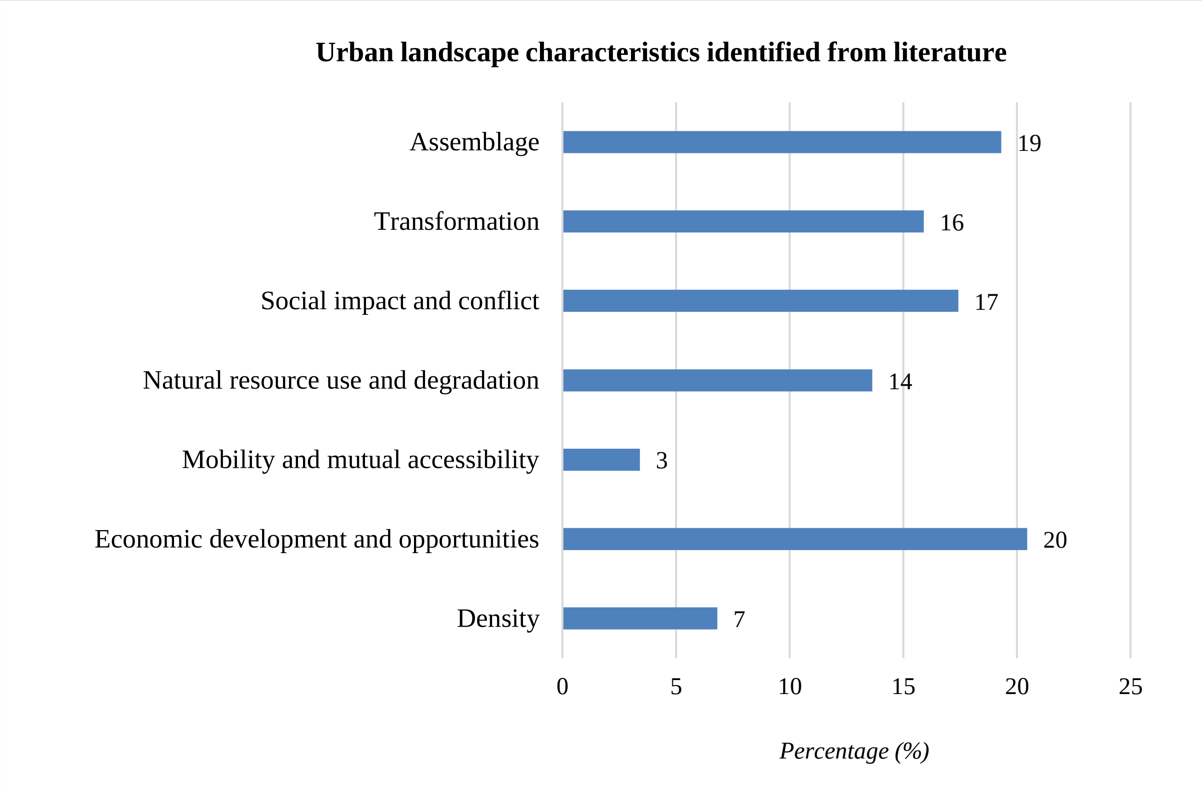

Figure 15: Urban landscape characteristics identified from the literature.

6.2.2. Content analysis: Questionnaire evaluation: context-specific conceptualisations of urban and post-mining characteristics

Following the evaluation of the characterisation of urban and post-mining in literature, data collected through the Google Forms survey and interviews were analysed using frequencies and percentages to determine whether literature characteristics have any bearing on how the Gauteng landscape is conceptualised as urban or post-mining. Figure 16 presents findings from the questionnaires from local experts regarding what constitutes a post-mining environment. Most (32%) of the local experts in the study identified post-mining landscapes as being defined by natural resource use and degradation, mostly citing mine waste and contamination. This is followed by derelict infrastructure and land and social impacts (both at 17%), economic development and economic decline (10%), rehabilitation (8%), infrastructural development (6%), post-mining landscapes as artificial and the leading cause of land transformation (both at 4%) and high population density (2%).

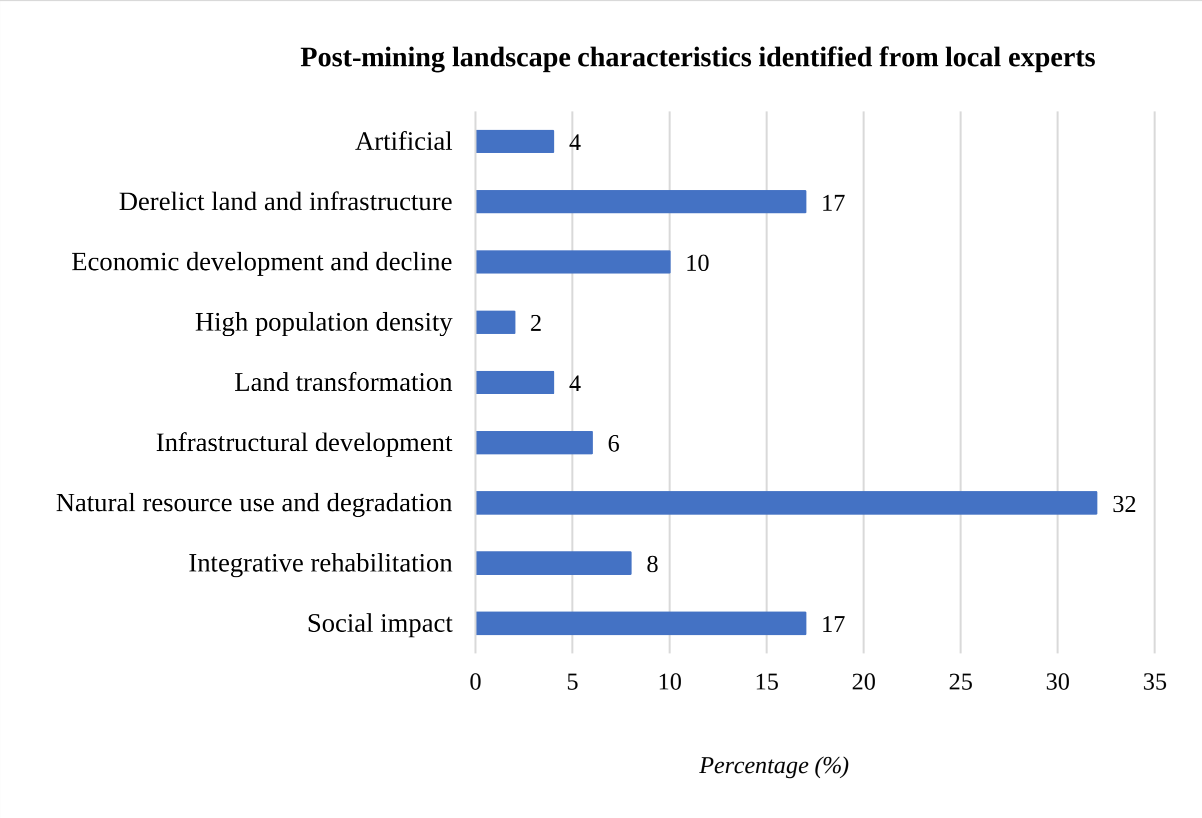

Figure 16: Post-mining landscape characteristics identified from local experts.

Similarly, Figure 17 presents the characterisations of the urban landscape in Gauteng, as identified from the survey sent to local experts. Thirty per cent of characteristics characterising urban landscapes are related to infrastructural development, followed by economic development and decline (21%), natural resource use and degradation (11%), informality, assemblage (both 8%), artificial (5%), economic decline, fragmentation, high population density, inequality, mining activity and integrative rehabilitation (3% respectively).

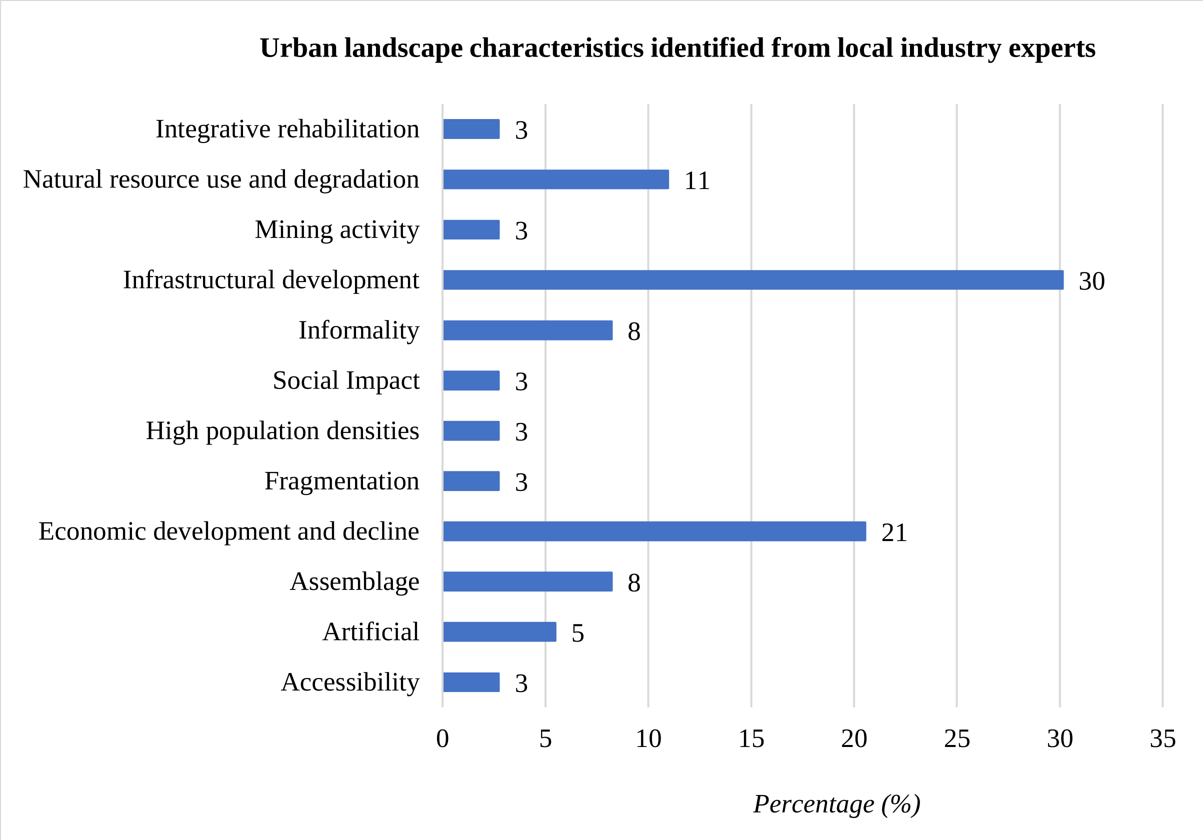

Figure 17: Urban landscape characteristics identified from contextual local experts.

When questioned on where their definitions of post-mining emanated, 22% of the local experts participating in the study reported that it stems from literature, 22% reported that it came from geological surveys and surveyor plans, and 22% reported that it came from historical maps. Only 11% reported that it emanates from the legislation. Additionally, 22% reported that their references to a post-mining landscape came from combining all four above sources. Similarly, when asked the same question, although on urban landscapes, 28% of the local experts reported that their references to urban landscapes come from policy and legislation documents, 22% reported it came from literature, and 22% reported that it came from maps and surveyor plans. In comparison, another 28% reported that it emanates from a combination of all mentioned reference sources.

However, while these experts agreed that literature and other archival material influenced their conceptualisations of these landscapes and their characteristics, some further noted that these were insufficient to represent the Gauteng landscape. Table 19 presents the information identified by local experts as missing from the definitions, conceptualisations and mapping of urban, mining and post-mining landscapes in Gauteng.

Table 19: Missing information in mapping post-mining and urban landscapes in Gauteng.

MISSING INFORMATION FROM POST-MINING AND URBAN CHARACTERISTICS	PERCENTAGE (%)
Lack of contextual data	24
Lack of information on the restoration of lost rights of humans and non-human ecologies	5
Lack of information on mining progression	10
Lack of information on stakeholder input and engagement	10
Lack of information on sustainable development	15
Lack of information on transdisciplinary land uses (post-mining, mining, urban)	14
Lack of socio-economic characteristics	10
Nothing missing	14
Total	**100**

Table 19 shows that 24% of local experts answered that urban and post-mining maps and their respective characterisations lack contextual information, with some respondents citing the unique political history of South Africa. On the other hand, 15% indicated a lack of information on sustainable development. A statement by one respondent and academic supports this view:

> *"Mining maps, and town planning schemes basically served to support extraction - these are either to support mining profits or property development. While the old maps and 1:50 000 topographic series did sometimes mark other features including indigenous structures, or water and wetlands, they were not aimed at any sort of sustainable development or restoration of lost rights of humans or non-human ecologies. Nor did they include temporal spaces such as ritual, animal migratory or ephemerally occupied sites. For the purposes of post-extractive life, or to limit sprawl, it is necessary to include data that notes and can be used to protect the remaining ecology of the area"(Respondent 1, Local expert, August 2021).*

As recorded in Table 19, 14% of responses indicated a lack of information on transdisciplinary land uses, stating that it was hard to distinguish between mining and urban. An issue that some respondents highlighted as being a key issue contributing to this was how the two landscapes are represented on maps. Additionally, some respondents suggested that some mining activities are on the subsurface. This contributes to the lack of clear boundaries of where the urban ends and post-mining and mining activities start. Another respondent states:

> *"Landscapes change along with changing activities, and there is no clear 'moment' when mining ends and post-mining starts, and similarly where mining stops and urban starts. There are clear extremes, but it is fuzzy in the middle. Mining landscapes could be understood as a mosaic landscape, with various activities and 'states' of mining existing at the same time. It is not always easy to define which is mining and which is*

not. Representation of these on a map captures a moment in time, although change over time can also be demonstrated." (Respondent 6, Local expert, August 2021)

Table 19 shows that 10% of responses related to a lack of information on mining progression, socio-economic characteristics, and stakeholder inputs, respectively. While 5% of responses related to the lack of information on human impact. Conversely, 14% of respondents reported that nothing was missing from the definition, conceptualisation and mapping of the post-mining and urban characteristics of the Gauteng landscape.

6.3. CONCEPTUAL FRAMEWORK OF A GIS-BASED FRAMEWORK FOR THE INTEGRATED MAPPING AND SPATIAL ANALYSES OF POST-MINING AND URBAN LANDSCAPE CHARACTERISTICS IN GAUTENG

This section entails conceptualising a framework for the integrated conceptualisation of post-mining and urban landscapes, followed by the practical application of the framework using three mapping techniques. The integration of landscape characteristics will be conducted using two sets of maps under each mapping method. This follows the identification of post-mining and urban landscape characteristics in sub-sections *6.2.1. Content analysis: Literature, legislation and other archival material* and *6.2.2. Content analysis: Questionnaire evaluation: context-specific conceptualisations of urban and post-mining characteristics*. These were used to start thinking through what a framework for the integrated conceptualisation of these landscapes in Gauteng would entail. The proposed framework is outlined below in section *6.3.2. The proposed framework for the integrated conceptualisation of Gauteng's post-mining and urban landscape characteristics* and *6.3.3. Spatial representation of Gauteng's integrated post-mining and urban landscape characteristics*.

6.3.1. Proposed conceptual framework for the integrated conceptualisation of Gauteng's post-mining and urban landscape characteristics

The post-mining and urban landscape characteristics outlined above were used to illustrate how these landscapes are conceptualised more broadly and at the contextual, Gauteng level. Figure 18 demonstrates characteristics of post-mining and urban landscapes (as identified from the literature) represented in red and blue, respectively. Figure 18 shows how several characteristics distinguish both landscapes under study. However, these characteristics are also affected by spatial and temporal factors. The characteristics of these two landscapes are placed on opposite ends to indicate that they are identified from the literature. Another space (indicated in purple), labelled "Gauteng landscape" in the middle of these characteristics, demonstrates the collapsed integrated post-mining and urban landscape characteristics as identified from the surveys with the local experts. These characteristics were collapsed and only represented once because the characterisations of the two landscapes were too similar in the Gauteng context, and as such, were only represented once to limit repetition.

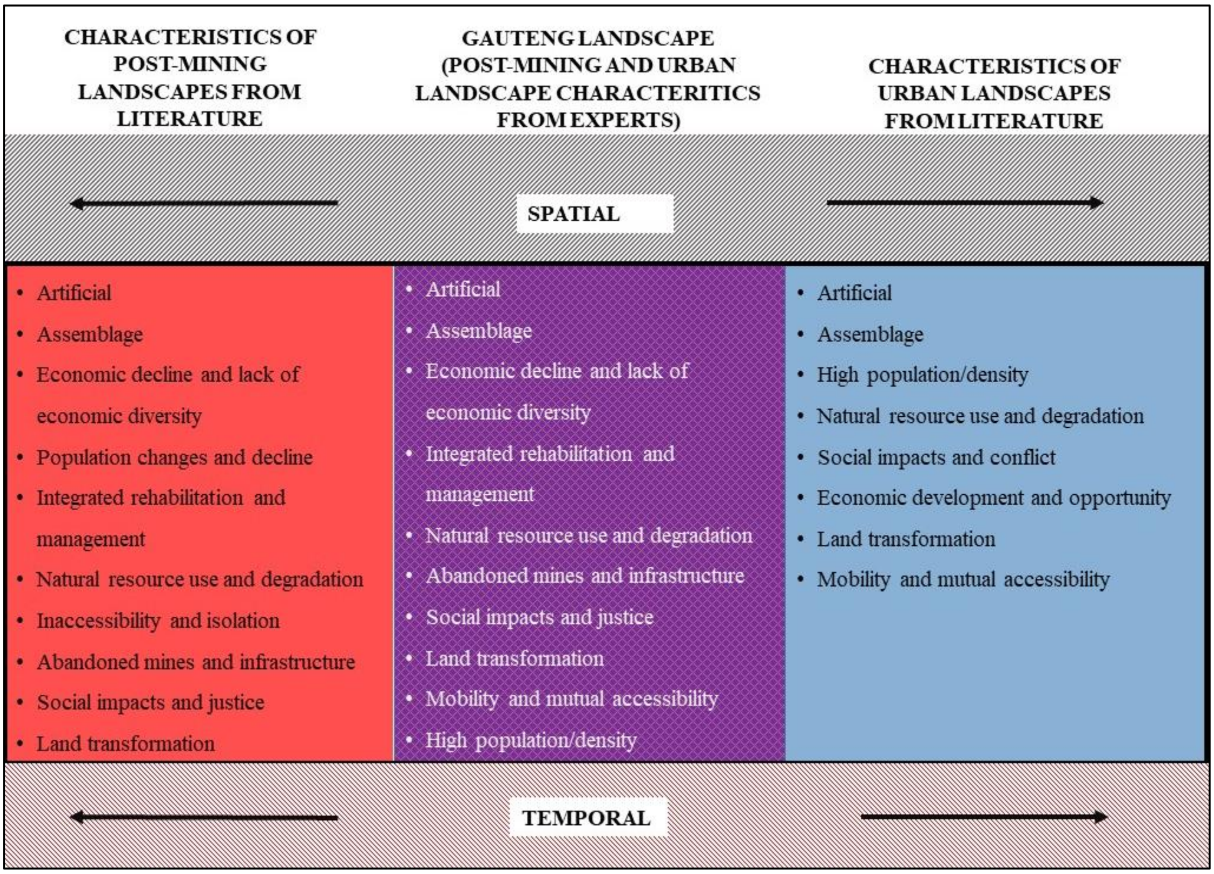

Figure 18: Conceptual framework for conceptualising post-mining and urban landscape characteristics. The post-mining and urban landscape characteristics as identified for the Gauteng landscapes are represented in purple.

However, contrary to other contexts where these landscapes coexist, albeit individually and away from each other, in Gauteng, these two landscapes can coexist even in the same spatial unit. Therefore, this suggests that these two landscapes overlap spatially. Figure 19 presents a simplified illustration of how the integrated conceptualisation and visualisation of Gauteng's post-mining and urban landscape characteristics would work if the two are considered to share a spatial unit. Post-mining landscape characteristics are again presented in red, and urban landscape characteristics are in blue. Figure 19 shows the two landscapes as two rhomboids (layers), a proxy for their respective spatial units. While mainly considered distinct in other settings, the responses from the surveys conducted with local experts indicated that the spatial features of post-mining and urban landscape characteristics would need to be added together for an integrated picture of the characteristics of the Gauteng landscape. The Gauteng integrated picture of both landscape characteristics in Gauteng is demonstrated in purple.

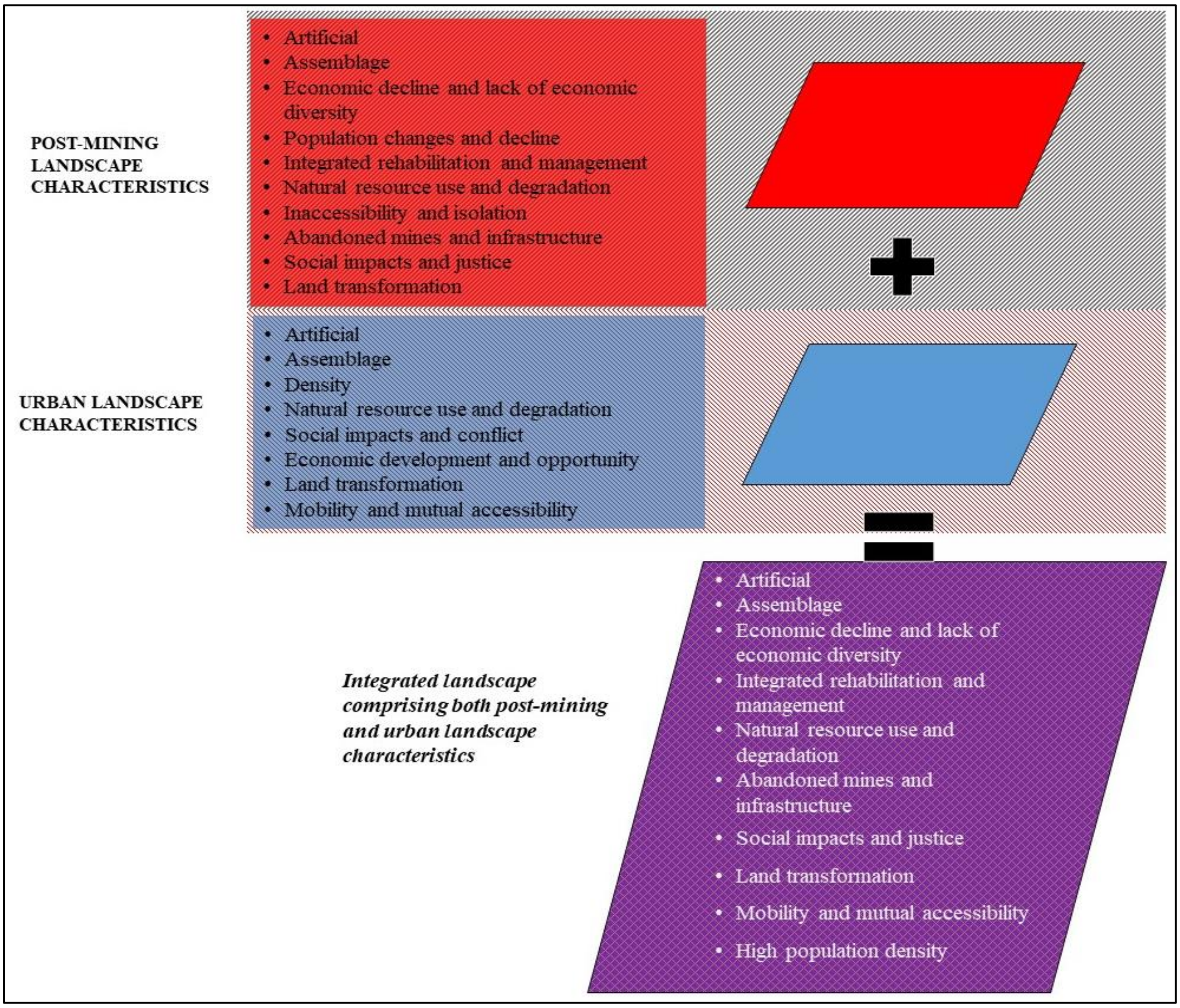

Figure 19: A proposed spatial framework for integrating post-mining and urban landscape characteristics on the same land unit.

6.3.2. Proposed GIS framework for the integrated conceptualisation of post-mining and urban landscapes

Based on the above characteristics, this research proposes a framework for integrating post-mining and urban landscape characteristics in Gauteng. The proposed framework comprises six major components. Specifically, the first two steps enable the identification of the landscape characteristics, the formulation of mapping criteria and weighting, identification and collection of data, which requires the spatial information database; the spatial information database provides all the assembled and pre-processed data as input for the mapping; the spatial representation of landscape characteristics using MCDM techniques - which offers a quantitative approach to integrating the post-mining and urban landscape characteristics identified from the literature; the resultant maps, and the validation and finalisation of the framework. These components would all work together to support the integration of landscape characteristics (Figure 20).

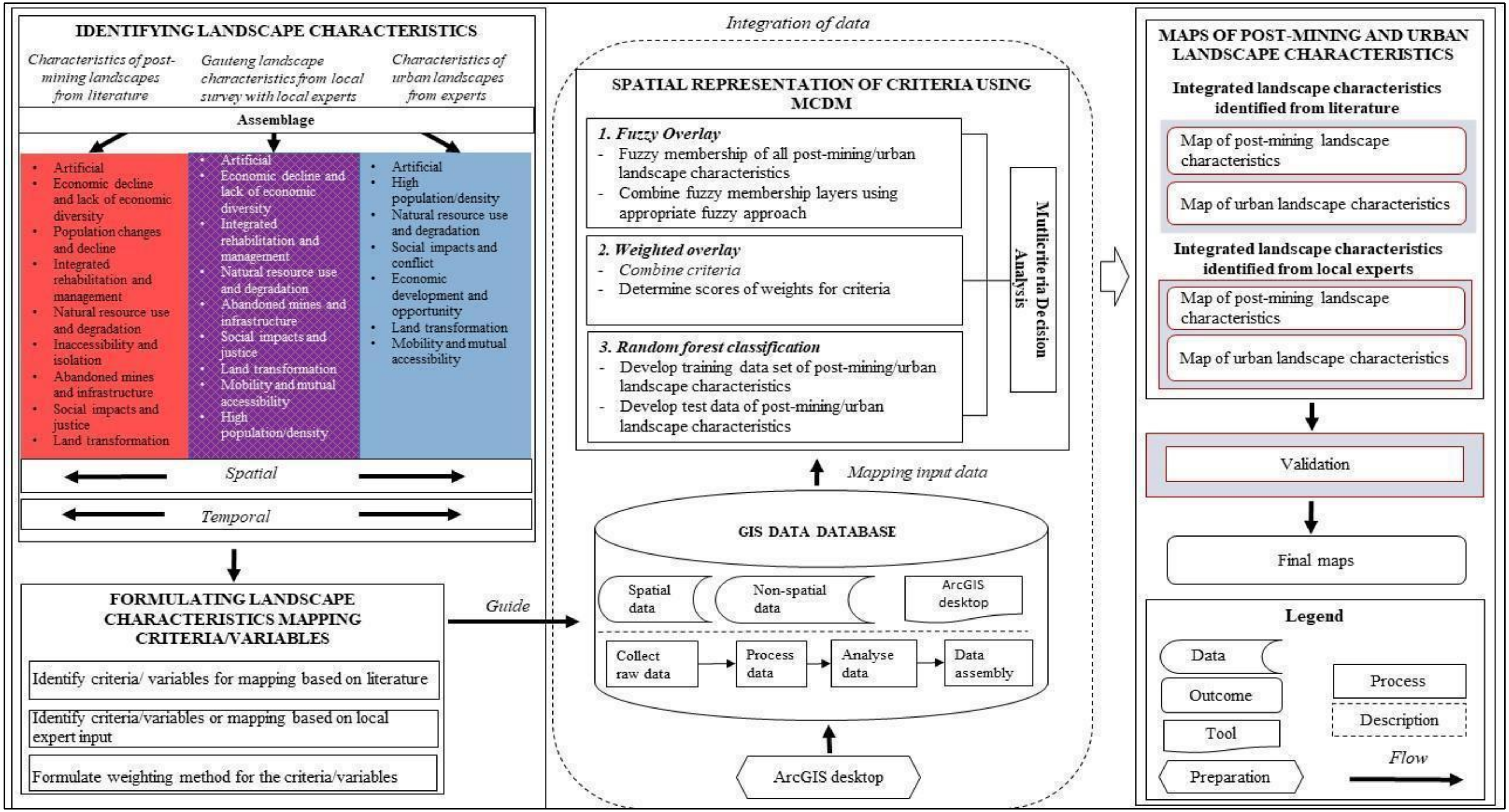

Figure 20: Proposed GIS framework for the integration of post-mining and urban landscape characteristics in Gauteng.

6.3.3. Spatial representation of Gauteng's integrated post-mining and urban landscape characteristics

The post-mining and urban landscape characteristics mentioned above were integrated through mapping using three mapping methods and guided by the framework mentioned above. This section is divided into three sub-sections, namely: fuzzy overlay (*6.3.3.1. Fuzzy overlay analysis),* weighted overlay (*6.3.3.2. Weighted overlay analysis)* and random forest classification (*6.3.3.3. Random forest classification),* where the results of each of the mapping exercises are presented. Each mapping exercise of these landscapes starts by first mapping based on findings from the content analysis of literature and other archival reference material (*6.2.1. Content analysis: Literature, legislation and other archival material)*. Following this, the mapping is repeated, incorporating the landscape characteristics identified from local experts (*6.2.2. Content analysis: Questionnaire evaluation: context-specific conceptualisations of urban and post-mining characteristics).* The latter includes additional post-mining[51] and urban[52] landscape characteristics.

6.3.3.1. Results of the fuzzy overlay analysis of post-mining and urban landscape characteristics

The results of the fuzzy overlay analysis of post-mining and urban landscape characteristics are outlined in sections *6.3.3.1.1. Fuzzy overlay of post-mining landscape characteristics* and *6.3.3.1.2. Fuzzy overlay of urban landscape characteristics* below. The criteria used to inform the fuzzy overlay analysis are outlined in section *5.5.2.1. Fuzzy overlay analysis of post-mining and urban landscape characteristics* in the previous chapter (Chapter 5). On these fuzzy overlay maps, fuzzy values closest to post-mining / mining-related and urban landscapes have a value of 1, and areas furthest have a value closest to 0.

6.3.3.1.1. Fuzzy overlay of post-mining characteristics

Map 12 presents the overlay or combination of the fuzzy membership layers of all the post-mining landscape characteristics identified from the literature (left) and local experts (right). The fuzzy overlay of post-mining landscape characteristics from literature (left) shows that the highest fuzzy values are most visible in areas traversing the central parts of the province, especially in areas such as Johannesburg, Krugersdorp and Benoni. However, other areas have high fuzzy values, such as areas in

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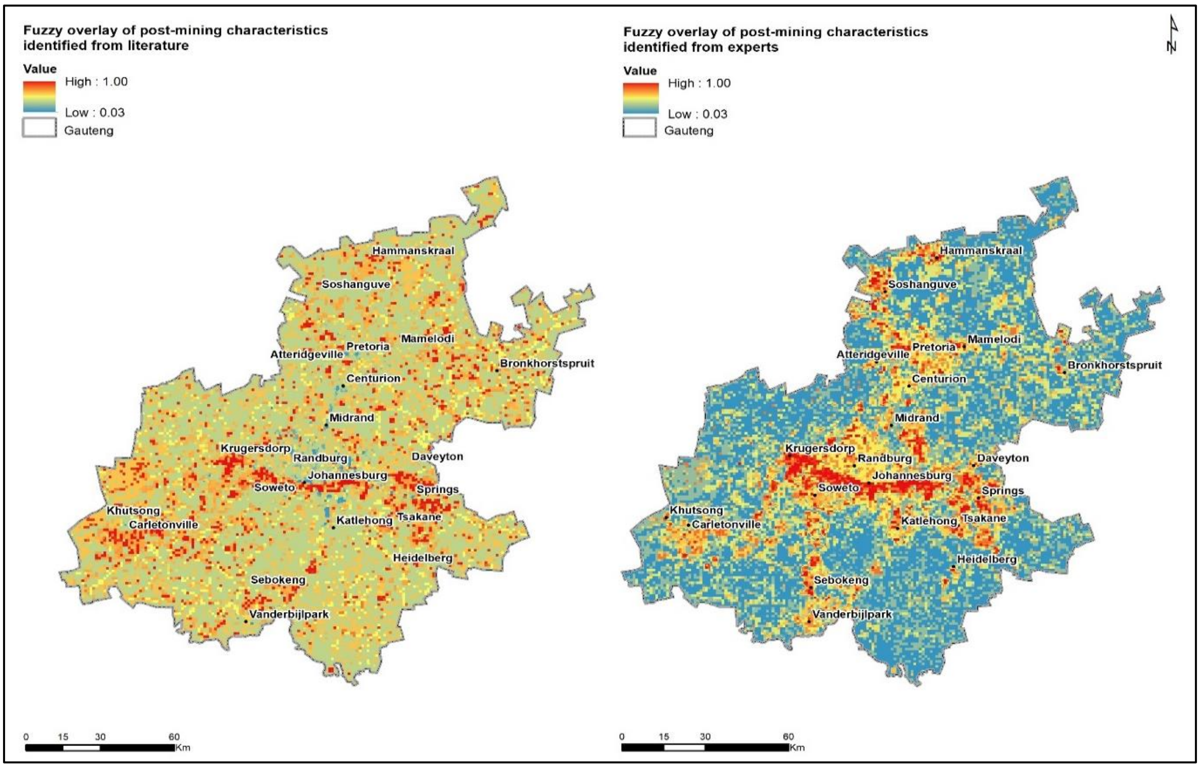
[51] The additional criteria are high business count per km^2, high industry count per km^2, high population count per km^2, high road accessibility, high rail accessibility and urban infrastructure.

[52] These additional characteristics are post-mining land uses, mining-related natural resource use and degradation (waste and contamination), mining-related infrastructure, integrated rehabilitation (post-mining land uses, development within slimes and dumps, etc.) and social impacts (proportion of the population within proximity to slimes and dumps, etc.)

the western, eastern and southern parts of the province, such as Carletonville, Khutsong and Vanderbijlpark (south of Sebokeng). A splattering of medium (orange) to high (red) values can also be seen across the province in areas other than the central, western and southern parts. By contrast, this map shows the lowest fuzzy values north concentrated at the core of the province, falling on either side of the high values traversing the mining belt, although mostly predominant in areas such as Randburg, Sandton (to the west of Alexandra), Centurion and Pretoria. The map also shows that the lowest and medium values mostly characterise the province.

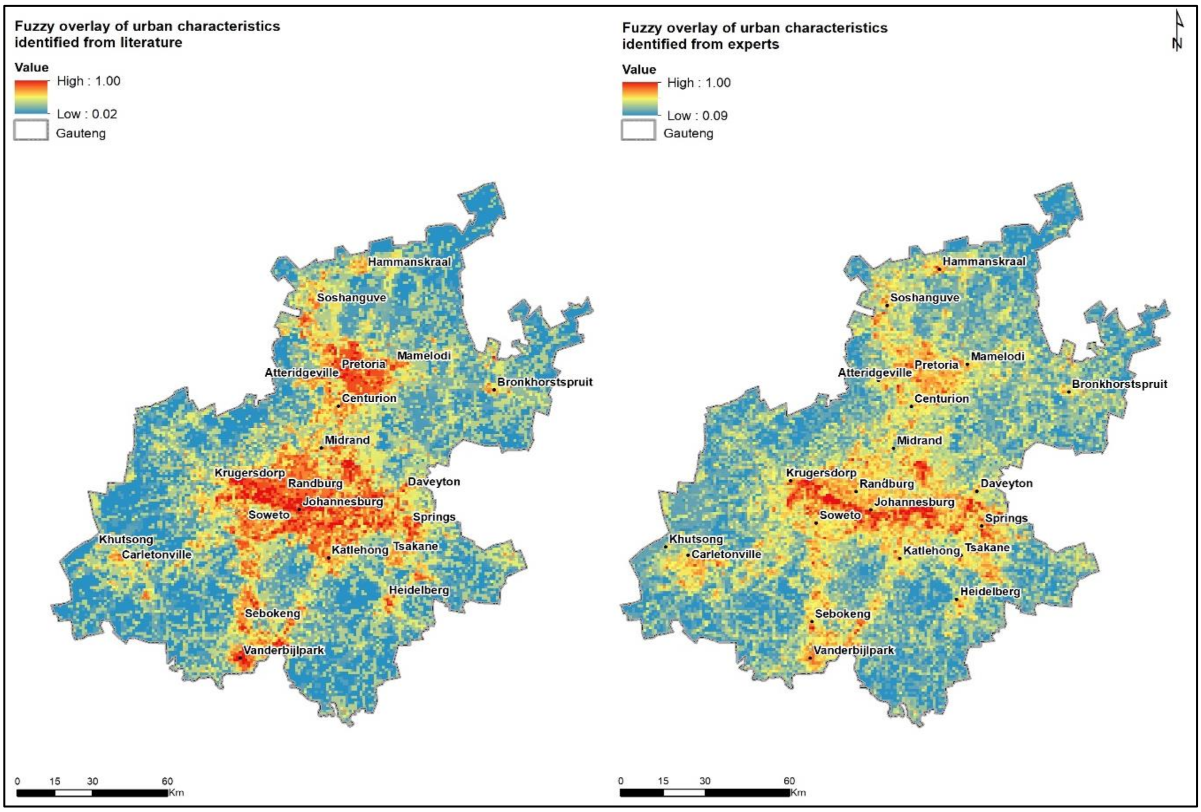


Map 12: Fuzzy overlay of post-mining landscape characteristics from literature (left) and experts (right).

By contrast, the fuzzy overlay and combination of all the fuzzy membership layers generated using post-mining landscape characteristics identified from local experts is presented on the right of the same map. While similar to those generated from literature, the post-mining landscape characteristics identified from local experts also comprised some additional criteria in this map. This map keeps some of the patterns already observed in the map on the left, such as the high fuzzy values in areas around the central parts of the province (Johannesburg, Krugersdorp, which is where the mining belt is located), in the west (Carletonville, Khutsong), in the east (Benoni) and the southern extremities of the province (Sebokeng). In contrast to the map on the left, this map also shows a concentration of high fuzzy values in areas such as Hammanskraal and Soshanguve in the northern extremities of the province, south of Sebokeng, in Heidelberg, and the areas on either side of the central parts of the province. These areas also have higher fuzzy values compared to the mapping of characteristics identified from the literature. Additionally, this map shows very low fuzzy values radiating outwards and located at the periphery.

6.3.3.1.2. Fuzzy overlay results of urban landscape characteristics

Map 13 presents the overlay or combination of the fuzzy membership layers of all the urban landscape characteristics identified from the literature on the left and local experts on the right. The map on the left, showing characteristics from literature, shows places with the highest fuzzy values at the province's core, especially in areas such as Johannesburg, Alexandra, Pretoria, Centurion, Sebokeng, Carletonville and their surroundings – highlighting the main economic nodes in the region. The high fuzzy values suggest high membership with urban landscape characteristics. However, the areas in the immediate surroundings of those areas that are characterised by high fuzzy values exhibit medium values (yellow). Additionally, the areas along the periphery of the province and just outside of the areas with medium values (yellow) are characterised by low values (blue). Low values are also observed just above Soweto. These low values suggest that these areas have low urban landscape characteristics.



Map 13: Fuzzy overlay of urban landscape characteristics from literature (left) and experts (right).

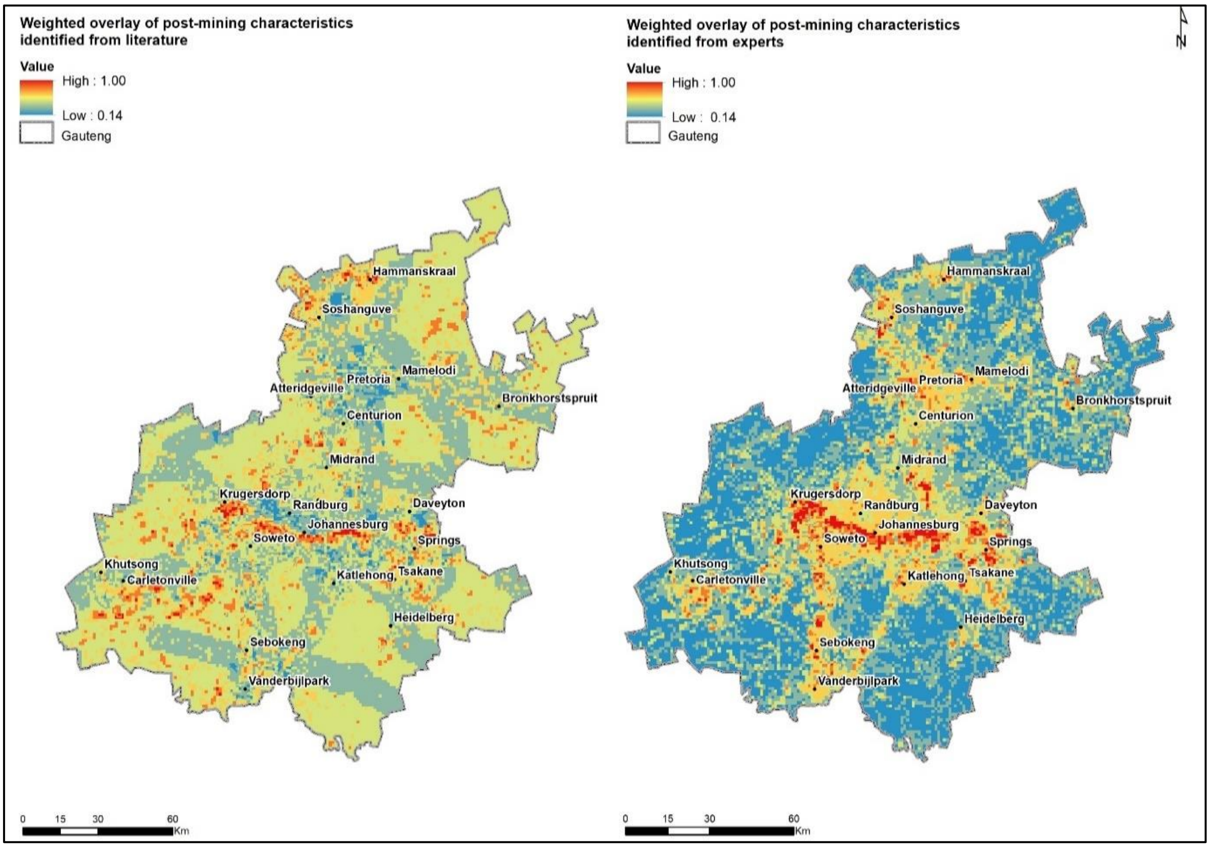
On the other hand, Map 13 also presents the fuzzy overlay and the combination of the urban landscape characteristics identified from local experts on the right. Similar to the previous map of urban landscape characteristics, the highest fuzzy values are observed at the province's core in areas such as Johannesburg, Benoni, Pretoria, Centurion, Carletonville, Sebokeng and Krugersdorp. However, the highest values are in the area traversing the central parts of the province, along the mining belt – as this mapping of the urban landscape characteristics includes mining-related characteristics. The areas immediately outside the areas characterised by the highest fuzzy values are characterised by medium values (yellows) and the periphery by low values (blue). However, while this map bears many similarities to the one on the left (characteristics from literature), there are visible differences. The main difference is that the area characterised by high fuzzy values at the core appears to decrease. Similarly, the areas characterised by the lowest values at the core also decrease in this map. At the same time, the area characterised by medium fuzzy values has increased.

6.3.3.2. Results of the weighted overlay analysis of post-mining and urban landscape characteristics

Weighted overlay is the second mapping technique investigated to demonstrate its capacity for integrating urban and post-mining characteristics. The results of the weighted overlay analysis of post-mining and urban landscape characteristics are outlined in sections *6.3.3.2.1. Weighted overlay of post-mining landscape characteristics* and *6.3.3.2.1. Weighted overlay of urban landscape characteristics* below. The criteria used to inform the weighted overlay analysis are outlined in section *5.5.2.2. Weighted overlay analysis of post-mining and urban landscape characteristics* in the previous chapter (Chapter 5). These maps use a graduated colour scale, ranging from red to blue. The areas on the map with values closest to post-mining/mining-related and urban landscape characteristics have high-weighted overlay values and are shown in shades closer to red. Areas with the lowest weighted overlay values, presented in shades closer to blue, have the least post-mining or urban landscape characteristics.

6.3.3.2.1. Weighted overlay of post-mining landscape characteristics

Map 14 presents a weighted overlay analysis of post-mining landscape characteristics identified from the literature on the left and local experts on the right. The map on the left, showing the characteristics identified from the literature, shows the highest weighted overlay values cut across the province east-westerly in areas such as Benoni, Johannesburg, Krugersdorp and Carletonville. Some areas in the north of the province, such as Hammanskraal, and areas in the south, such as Vanderbijlpark (south of Sebokeng), also show high values. The map also presents random high weighted overlay values across the province outside those mentioned in areas such as Diepsloot and south of Heidelberg. Most of the province is characterised by medium (yellow/green) to low values (blue). The medium values are mostly observed in areas such as Alexandra (and Sandton to the left of it), Centurion, Daveyton, Mamelodi, Atteridgeville, Tembisa, Soweto and Orange Farm. By contrast, low values are observed in Randburg, Khutsong, Katlehong, Vanderbijlpark (south of Sebokeng) and Pretoria. Low weighted overlay values are also observed along what seems to be transport routes – noting that literature suggests that post-mining landscapes are inaccessible.



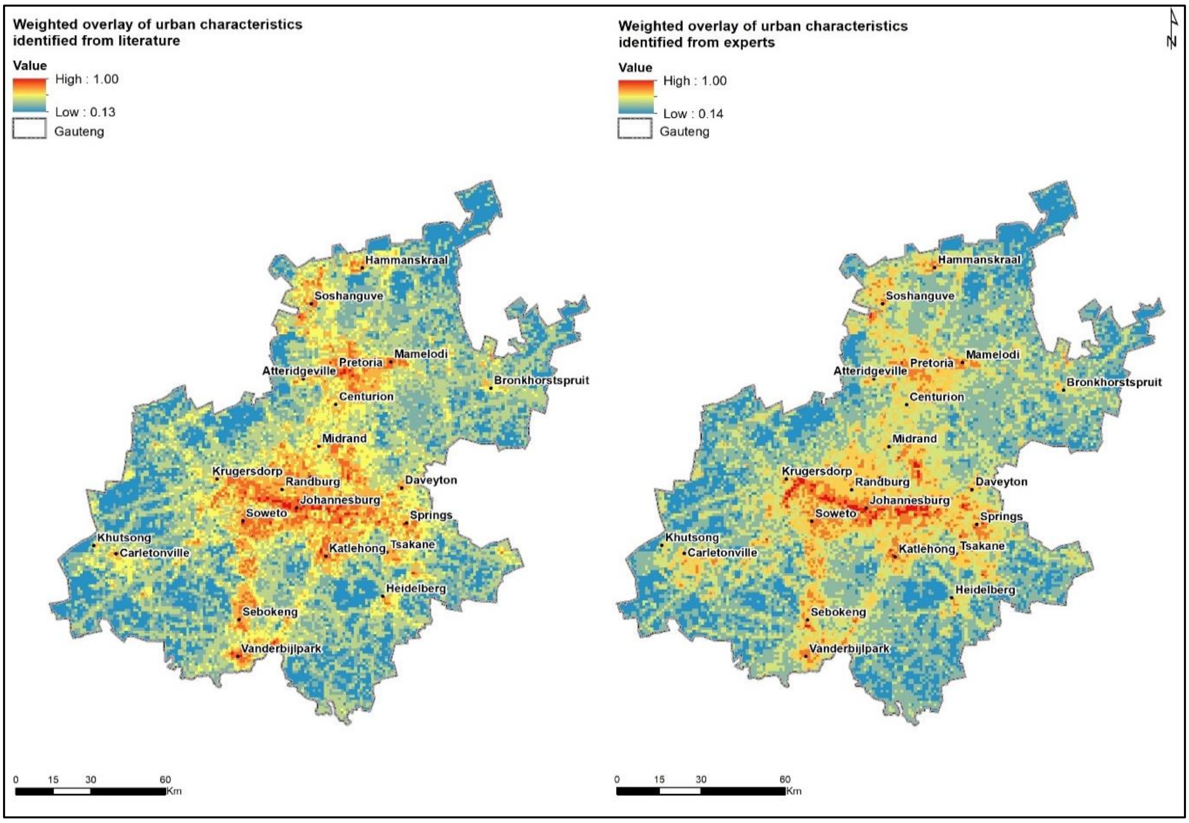
Map 14: Weighted overlay of post-mining landscape characteristics from literature (left) and experts (right).

By contrast, although using the same symbology as the map on the left to be comparable, the map on the right presents a different picture. This map presents the weighted overlay of post-mining landscape characteristics identified from local experts. This map keeps some of the patterns already observed in Map 12[53], such as the high weighted overlay values in areas around the central parts of the province (Johannesburg, Krugersdorp, which is where the mining belt is located), in the west (Carletonville, Khutsong), in the east (Benoni) and the southern extremities of the province (Sebokeng). This map also shows a concentration of high weighted overlay values in areas such as Hammanskraal and Soshanguve in the northern extremities of the province, south of Sebokeng, in Heidelberg, and the areas on either side of the central parts of the province compared to the map on the left. However, in contrast to the previous map, this map shows a concentration of just below the highest (orange) to medium values (green) in the immediate surroundings of areas with the highest values, which also happens to cover the province's core. Additionally, this map shows very low weighted overlay values radiating outwards and mostly at the periphery of the province.

[53] Specifically, the map on the left, which presents a fuzzy overlay of the urban landscape characteristics.

6.3.3.2.2. Weighted overlay of urban characteristics

Map 15 presents the weighted overlay of urban landscape characteristics identified from the literature on the left and local experts on the right. The map on the left, showing the characteristics identified from the literature, shows the highest values at the province's core in areas such as Johannesburg, Benoni, Pretoria, Centurion, Carletonville, Sebokeng and Krugersdorp and their surroundings – highlighting the main economic nodes in the region. However, the areas in the immediate surroundings of those areas that are characterised by high weighted overlay values exhibit medium values (yellow). Additionally, the areas along the periphery of the province and just outside of the areas with medium weighted overlay values (yellow) are characterised by low values (blue). The low values are mostly observed at the northern-most tip of the province and the southwestern and eastern parts of the province. Some low values are visible just above Soweto, next to the mining belt.



Map 15: Weighted overlay map of urban landscape characteristics from literature (left) and experts (right).

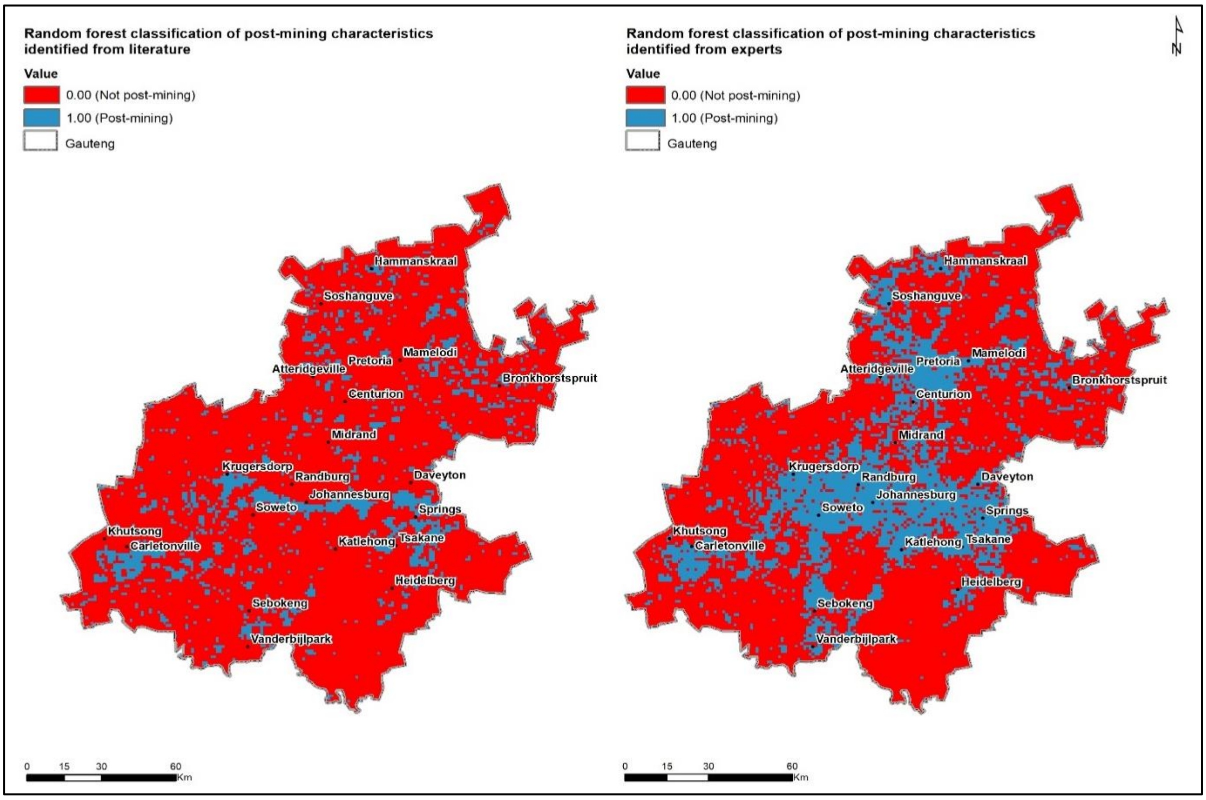
On the other hand, the map on the right presents a weighted overlay of urban landscape characteristics identified from local experts and shows a different picture from the previous map. Similar to the previous map, this map shows high values cutting across the province in an east-westerly direction in areas such as Benoni, Johannesburg, Krugersdorp and Carletonville, and in northern areas such as Hammanskraal, and southern areas such as Vanderbijlpark (south of Sebokeng). Noting, however, that the highest weighted overlay values are in the area traversing the central parts of the province, along the mining belt – as this mapping of the urban landscape characteristics includes mining-related characteristics. Also similar to the previous map, this map shows a smaller spatial footprint of low weighted overlay value areas. However, this map shows a concentration of just below the highest (orange) to medium weighted overlay values (green) in the immediate surroundings of areas with the highest values, which also covers the province's core. These medium and high values characterise a similar spatial footprint to the previous map. Despite these similarities, however, the map has a smaller footprint of high weighted overlay values than the previous one. For example, the high weighted overlay values observed in the map on the left are less pronounced in this map in areas such as Pretoria, Soweto, Katlehong and Randburg.

6.3.3.3. Results of the random forest classification of post-mining and urban landscape characteristics

Random Forest classification is the third mapping technique explored for mapping the integration of urban and post-mining landscape characteristics in Gauteng. The results of the random forest classification of post-mining and urban landscape characteristics are outlined in sections *6.3.3.3.1. Random forest classification of post-mining landscape characteristics* and *6.3.3.3.2. Random forest classification of urban landscape characteristics* below. The criteria used to inform the weighted overlay analysis are outlined in section *5.5.2.3. Random forest classification analysis of post-mining and urban landscape characteristics* in the previous chapter (Chapter 5). These maps use a graduated colour scale, ranging from red to blue. The areas on the map with values closest to post-mining/mining-related and urban landscape characteristics have high predicted values and are shown in red. Therefore, areas with the lowest predicted values far from post-mining or urban landscape characteristics are represented in blue.

6.3.3.3.1. Random forest classification of post-mining classifications

Map 16 shows the positive classification (in blue) of grid cells characterised by post-mining landscape characteristics identified from the literature on the left and local experts on the right. The map on the left, using characteristics identified from the literature, shows that the positive classification of grid cells mainly traverses along the central parts of the province in an east-westerly direction in areas such as Johannesburg, Krugersdorp and Benoni, Carletonville, Khutsong and Vanderbijlpark (south of Sebokeng). However, the map also shows positive classification as post-mining landscape randomly placed areas across the province. For example, this is in areas such as east of Mamelodi in the north-eastern-most part of the province and the north-western-most part around Hammanskraal. By contrast, most of the province is classified not as post-mining. These areas are grid cells with either no values or values below the 50% mark.

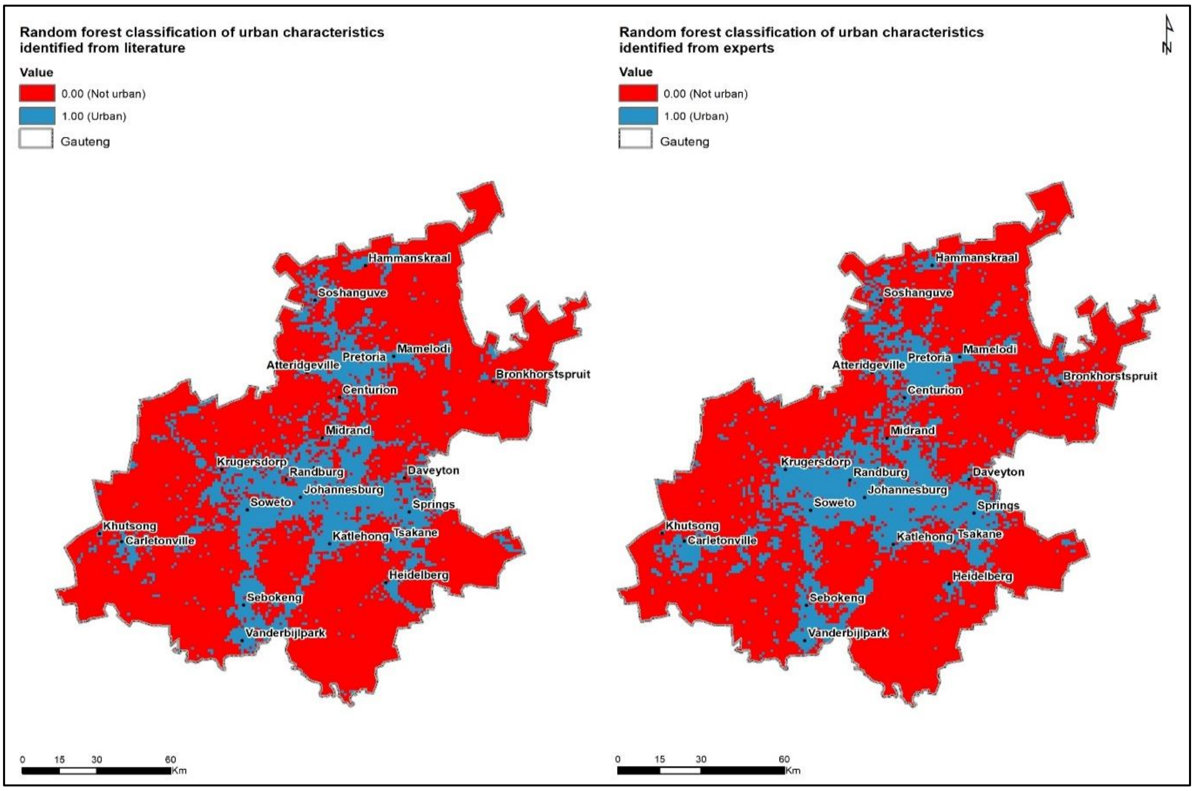


Map 16: Random forest classification of post-mining landscape characteristics from literature (left) and experts (right).

In contrast to the map on the left, the map on the right shows the positive classification (indicated in blue) of grid cells characterised by post-mining landscape characteristics identified from local experts. This shows the positive classification of grid cells mainly concentrated at the core of the traversing along the central parts of the province in an east-westerly direction, in areas such as Johannesburg, Krugersdorp and Benoni, Carletonville, Khutsong and Vanderbijlpark (south of Sebokeng). However, the map also shows positive classification as post-mining landscape randomly placed areas across the province. This is, for example, in areas such as east of Mamelodi in the north-eastern-most part of the province and the north-western-most part around Hammanskraal. By contrast, most of the province is classified not as post-mining.

6.3.3.3.2. Random forest classification of urban characteristics

Map 17 shows the positive classification (indicated in blue) of grid cells characterised by urban landscape characteristics as identified from the literature on the left and local experts on the right. The map on the left (characteristics from literature) shows the positive classification of grid cells mainly at the core of the province and observed in areas such as Randburg, Alexandra, Sebokeng, Johannesburg, Krugersdorp, Benoni, Carletonville, Khutsong, Vanderbijlpark (south of Sebokeng), Pretoria, Hamanskraal and their surrounds. The map also shows positive classification along what appears to be the transportation routes across the province. However, despite these high values, this map also shows that most of the province is classified not as urban or characterised by urban landscape characteristics. Low values are mostly observed at the periphery of the province. However, low values can also be observed in small areas just above Soweto, areas surrounding Khutsong, west of Krugersdorp, some areas near Daveyton, etc.

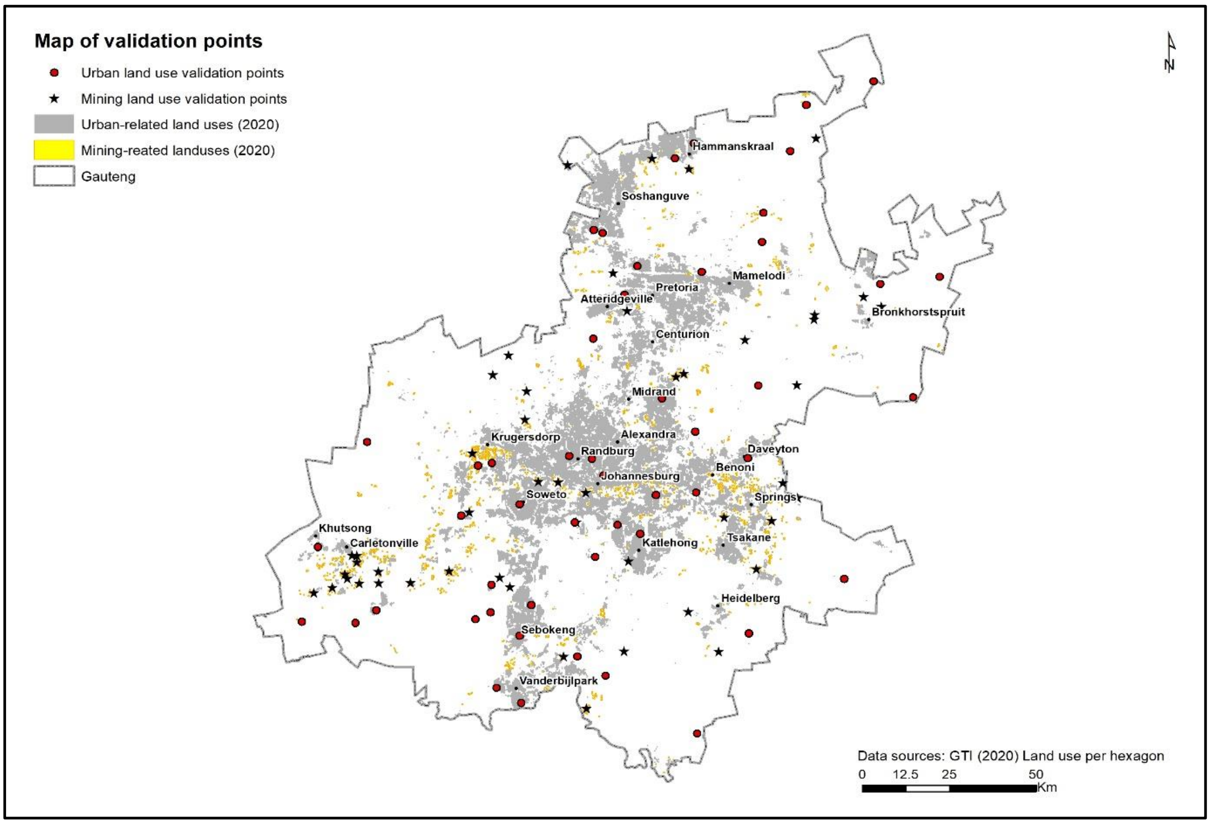


Map 17: Random forest classification of urban landscape characteristics from literature (left) and experts (right).

In contrast to the map on the left, this map shows the positive classification (indicated in blue) of grid cells characterised by urban landscape characteristics identified from local experts. Similarly to the previous map, this map shows the positive classification of grid cells mainly at the core of the province and observed in areas such as Randburg, Alexandra, Sebokeng, Johannesburg, Krugersdorp, Benoni, Carletonville, Khutsong, Vanderbijlpark (south of Sebokeng), Pretoria, Hamanskraal and their surroundings. This map shows a positive classification of grid cells as characterised by urban landscape characteristics along transport routes. This map also shows that despite these high values, most of the province is classified as not urban or characterised by urban landscape characteristics. This map shows that the positive classification of grid cells characterised by urban landscape characteristics has a slightly larger spatial footprint than the previous.

6.4. VALIDATION OF THE FRAMEWORK

Once the post-mining and urban landscape characteristics were mapped, each mapping result was evaluated using four evaluation and validation measures outlined in section *5.5.3. Testing and validation of the mapping of landscape characteristics (Chapter 5).* The resultant outputs from the mapping were evaluated to assess the merits of each mapping method for integrating post-mining and urban landscape characteristics. The first two evaluation methods cross-evaluate the mapped results versus the reference data through a confusion error matrix. Map 18 shows the distribution of the intentional validation points, the post-mining and urban land use characteristics they are based on, and the location of the random validation points. The third method evaluates the proportion of model values that meet the following ranges: 0 – 25%, 26 – 50%, 50 – 75% and 76 – 100% of the highest possible value for each mapping result. These two point datasets were used as the validation layers to extract values at point locations across all three models and their relevant criteria. The fourth method, image differencing, was used on the mapping results to check for differences in the literature and expert-based maps. Each of the validation results are discussed below.



Map 18: Map of validation points.

6.4.1. Confusion error accuracy of assessment of mapping of post-mining and urban landscape characteristics

The results of the accuracy assessments conducted on the mapping of post-mining and urban landscape characteristics mentioned above are presented in this section. This section is divided into three sub-sections: *6.4.1.1.Accuracy assessment of fuzzy overlay mapping post-mining and urban landscape characteristics*, *6.4.1.2. Accuracy assessment of weighted overlay mapping of post-mining and urban landscape characteristics* and *6.4.1.3. Accuracy assessment of the random forest classification of post-mining and urban landscape characteristics*. Each section starts by presenting the accuracy assessment results of characteristics identified from the literature, followed by those of characteristics identified by experts.

6.4.1.1. Accuracy assessment of fuzzy overlay for mapping post-mining and urban landscape characteristics

Table 20 shows the accuracy assessment results of the fuzzy overlay analysis and mapping of post-mining landscape characteristics. The table shows that the overlay accuracy results of the characteristics identified from the literature (72%) are higher than those identified from experts (64%). The user accuracy is variable for those pixels identified as mining land use and those classified as not mining land use. The table also shows that the user accuracy for areas not classified as mining land use is higher in mapping characteristics based on literature compared to experts. At the same time, the inverse is true for those pixels identified as mining land use. The producer's accuracy for characteristics identified from experts is higher for those pixels classified as not mining land use than in mapping characteristics from the literature. However, the inverse is true for those pixels characterised as mining land use.

Table 20: Comparison of accuracy assessment of fuzzy overlay post-mining characteristics from literature and experts.

FUZZY OVERLAY OF POST-MINING LANDSCAPE CHARACTERISTICS IDENTIFIED FROM THE LITERATURE					**FUZZY OVERLAY OF POST-MINING LANDSCAPE CHARACTERISTICS IDENTIFIED FROM EXPERTS**			
Class	Not mining land use	Mining land use	Total reference points		Class	Not mining land use	Mining land use	Total reference points
Not mining land use	18	7	25		Not mining land use	24	17	41
Mining land use	7	18	25		Mining land use	1	8	9
Total classified points	25	25	50		**Total classified points**	25	25	50
Total correct reference points	36				**Total correct reference points**	32		
Total true reference points	50				**Total true reference points**	50		

Per cent accuracy	72				**Per cent accuracy**	64		
Users accuracy					**Users accuracy**			
Not mining land use	72				Not mining land use	59		
Mining land use	72				Mining land use	89		
Producer's accuracy					Producers accuracy			
Not mining land use	72				Not mining land use	96		
Mining land use	72				Mining land use	32		

On the other hand, Table 21 shows the accuracy assessment results of the fuzzy overlay analysis and mapping of urban landscape characteristics. Similarly, the table shows that the overall accuracy results of the characteristics identified from the literature (70%) are higher than those identified from experts (64%). The table also shows that the user accuracy for pixels not classified as urban land use is higher in mapping characteristics based on literature compared to experts. At the same time, the inverse is true for those pixels identified as urban land use. The producer accuracy for mapping characteristics identified from experts is higher for those pixels classified as not urban land use than those from literature; however, the inverse is true for those pixels characterised as mining land use.

Table 21: Comparison of accuracy assessment of fuzzy overlay of urban landscape characteristics from literature and experts.

FUZZY OVERLAY OF URBAN LANDSCAPE CHARACTERISTICS IDENTIFIED FROM THE LITERATURE					**FUZZY OVERLAY OF URBAN LANDSCAPE CHARACTERISTICS IDENTIFIED FROM EXPERTS**			
Class	Not urban land use	Urban land use	Total reference points		Class	Not urban land use	Urban land use	Total reference points
Not urban land use	19	9	28		Not urban land use	22	14	36
Urban land use	6	16	22		Urban land use	3	11	14
Total classified points	25	25	50		**Total classified points**	0	25	50
Total correct reference points	35				**Total correct reference points**	33		
Total true reference points	50				**Total true reference points**	50		
Per cent accuracy	70				**Per cent accuracy**	64		
Users accuracy					**Users accuracy**			

Not urban land use	68				Not urban land use	61		
Urban land use	73				Urban land use	79		
Producers accuracy					**Producers accuracy**			
0	76				0	96		
1	64				1	44		

6.4.1.2. Accuracy of weighted overlay analysis of post-mining and urban landscape characteristics

Table 22 shows the accuracy assessment results of the weighted overlay analysis and mapping of post-mining landscape characteristics. The table shows that the overall accuracy results of the characteristics identified from experts are higher (46%) than those identified from the literature (40%). The user accuracy is higher in the map of post-mining landscapes from literature than from the experts. Noting here that the producer accuracy is higher for those pixels classified as not mining land use in mapping post-mining characteristics identified from experts than those from literature. However, the inverse is true for those pixels classified as mining land use.

Table 22: Comparison of accuracy assessment of weighted overlay of post-mining landscape characteristics from literature and experts.

WEIGHTED OVERLAY OF POST-MINING LANDSCAPE CHARACTERISTICS IDENTIFIED FROM THE LITERATURE					**WEIGHTED OVERLAY OF POST-MINING LANDSCAPE CHARACTERISTICS IDENTIFIED FROM EXPERTS**			
Class	Not mining land use	Mining land use	Total reference points		Class	Not mining land use	Mining land use	Total reference points
Not mining land use	19	14	33		Not mining land use	20	22	42
Mining land use	6	11	17		Mining land use	5	3	8
Total classified points	25	25	50		**Total classified points**	25	25	50
Total correct reference points	20				**Total correct reference points**	23		
Total true reference points	50				**Total true reference points**	50		
Per cent accuracy	40				**Per cent accuracy**	46		
Users accuracy					**Users accuracy**			
Not mining land use	58				Not mining land use	48		
Mining land use	65				Mining land use	38		

Producers accuracy					**Producers accuracy**			
0	76				0	80		
1	44				1	12		

Similarly, Table 23, although showing the accuracy assessment results of urban landscape characteristics, indicates that the overall accuracy results of the characteristics identified from experts are higher (80%) than those identified from the literature (76%). User accuracy is higher in the map of urban landscapes from experts than in the literature. At the same time, the producer accuracy is almost similar in both the maps of the urban landscape characteristics. However, it is lower for those pixels classified as not urban land use in mapping urban landscape characteristics identified from literature than those from the experts. In contrast, the inverse is true for those pixels classified as urban land use.

Table 23: Comparison of accuracy assessment of weighted overlay of urban landscape characteristics from literature and experts.

WEIGHTED OVERLAY OF URBAN LANDSCAPE CHARACTERISTICS IDENTIFIED FROM THE LITERATURE					**WEIGHTED OVERLAY OF URBAN LANDSCAPE CHARACTERISTICS IDENTIFIED FROM EXPERTS**			
Class	Not urban land use	Urban land use	Total reference points		Class	Not urban land use	Urban land use	Total reference points
Not urban land use	22	9	31		Not urban land use	21	6	27
Urban land use	3	16	19		Urban land use	4	19	23
Total classified points	25	25	50		**Total classified points**	25	25	50
Total correct reference points	38				**Total correct reference points**	40		
Total true reference points	50				**Total true reference points**	50		
Per cent accuracy	76				**Per cent accuracy**	80		
Users accuracy					**Users accuracy**			
Not urban land use	71				Not urban land use	78		
Urban land use	84				Urban land use	83		
Producers accuracy					**Producers accuracy**			
0	88				0	84		
1	64				1	76		

6.4.1.3. Accuracy assessment of random forest classification of post-mining and urban landscape characteristics

Table 24 shows the accuracy assessment results of the random forest classification and mapping of post-mining landscape characteristics. The overall accuracy results of the characteristics identified from the literature are higher (66%) than those identified from the experts (30%). Unlike in previous map results, where there was some variability in the user and producer accuracy results, this table shows the same for the user and producer accuracy for both the pixels classified as mining and not mining land use.

Table 24: Comparison of accuracy assessment of random forest classification of post-mining landscape characteristics from literature and experts.

RANDOM FOREST CLASSIFICATION OF POST-MINING LANDSCAPE CHARACTERISTICS IDENTIFIED FROM THE LITERATURE					**RANDOM FOREST CLASSIFICATION OF POST-MINING LANDSCAPE CHARACTERISTICS IDENTIFIED FROM EXPERTS**			
Class	Not mining land use	Mining land use	Total reference points		Class	Not mining land use	Mining land use	Total reference points
Not mining land use	19	11	30		Not mining land use	10	20	30
Mining use	6	14	20		Mining use	15	5	20
Total classified points	25	25	50		**Total classified points**	25	25	50
Total correct reference points	33				**Total correct reference points**	15		
Total true reference points	50				**Total true reference points**	50		
Per cent accuracy	66				**Per cent accuracy**	30		
Users accuracy					**Users accuracy**			
Not mining land use	63				Not mining land use	33		
Mining use	70				Mining use	25		
Producers accuracy					**Producers accuracy**			
Not mining land use	76				Not mining land use	40		
Mining use	100				Mining use	20		

Table 25 shows the accuracy assessment results of the random forest classification and mapping of urban landscape characteristics. The table shows that the overall accuracy results of the characteristics identified from experts are higher (80%) than those identified from the literature (76%). Similar to the previous map results, this table shows the same for user and producer accuracy for both the pixels classified as urban and not urban land use.

Table 25: Comparison of accuracy assessment of random forest classification of urban landscape characteristics.

RANDOM FOREST CLASSIFICATION OF URBAN LANDSCAPE CHARACTERISTICS IDENTIFIED FROM THE LITERATURE					**RANDOM FOREST CLASSIFICATION OF URBAN LANDSCAPE CHARACTERISTICS IDENTIFIED FROM EXPERTS**			
Class	Not urban land use	Urban land use	Total reference points		Class	Not urban land use	Urban land use	Total reference points
Not urban land use	21	8	29		Not urban land use	21	6	27
Urban land use	4	17	21		Urban land use	4	19	23
Total classified points	25	25	50		**Total classified points**	25	25	50
Total correct reference points	38				**Total correct reference points**	40		
Total true reference points	50				**Total true reference points**	50		
Per cent accuracy	76				**Per cent accuracy**	80		
Users accuracy					**Users accuracy**			
Not urban land use	72				Not urban land use	78		
Urban land use	81				Urban land use	83		
Producers accuracy					**Producers accuracy**			
Not urban land use	84				Not urban land use	84		
Urban land use	68				Urban land use	76		

An observation of accuracy results across all three methods for mapping and integrating the post-mining and urban landscape characteristics shows that the mapped accuracy results are higher in those mapping post-mining landscape characteristics identified from literature than experts, except those maps generated using a weighted overlay. On the other hand, the accuracy results across all three methods for mapping and integrating the urban landscape characteristics show that the mapped accuracy results are higher in those mapping urban landscape characteristics identified from experts than in the literature, except those maps generated using a fuzzy overlay. These findings are further discussed in Chapter 7.

6.4.2. Directed point samples on mining and urban-related hexagonal land use

The two validation points were cross-checked against the final resultant outputs of the fuzzy overlay, weighted overlay and random forest classification maps of post-mining and urban landscape characteristics. All intentional points (generated using the reference data) were expected to have high values across all the post-mining and urban landscape characteristics map outputs. The results of the cross-checking are presented in Table 26. The table is then ordered with the 20 intentionally selected points at the top, followed by the 20 random points. The findings are grouped by mapping method, mapped landscape characteristics and colour-coded. The map values at each intentional and random point location were recorded in the table. Map values were colour-coded based on four value ranges for comparability: 0 – 25% in blue, 26 – 50% in green, 51 - 75% in yellow and 76 - 100% of 1 (the highest value) in red.

Table 26: Values at each mapped point across fuzzy overlay, weighted overlay and random forest classification results.

Selected Cell Location	**POST-MINING CHARACTERISTICS (LITERATURE)**			**POST-MINING CHARACTERISTICS (EXPERTS)**			**URBAN CHARACTERISTICS (LITERATURE)**			**URBAN CHARACTERISTICS (EXPERTS)**		
	Fuzzy Overlay	Weighted overlay	Random forest	Fuzzy Overlay	Weighted overlay	Random	Fuzzy Overlay	Weighted overlay	Random forest	Fuzzy Overlay	Weighted overlay	Random forest
Intentional 1	0.49	0.14	1.00	0.19	0.29	1.00	0.80	0.63	1.00	0.53	0.57	1.00
Intentional 2	0.51	0.43	1.00	0.58	0.43	1.00	0.75	0.75	0.00	0.83	0.86	1.00
Intentional 3	0.54	0.57	1.00	0.46	0.57	1.00	0.73	0.75	1.00	0.51	0.71	1.00
Intentional 4	0.27	0.43	1.00	0.05	0.14	1.00	0.80	0.50	1.00	0.45	0.57	1.00
Intentional 5	0.39	0.43	1.00	0.31	0.43	1.00	0.46	0.75	1.00	0.60	0.71	1.00
Intentional 6	0.54	0.43	1.00	0.58	0.57	1.00	0.70	0.50	1.00	0.43	0.57	1.00
Intentional 7	0.57	0.71	1.00	0.59	0.57	1.00	0.68	0.63	1.00	0.48	0.57	1.00
Intentional 8	0.73	0.43	0.00	0.47	0.43	1.00	0.26	0.75	1.00	0.47	0.57	1.00
Intentional 9	0.76	0.71	1.00	0.61	0.43	0.00	0.26	0.50	1.00	0.24	0.43	0.00
Intentional 10	0.51	0.29	0.00	0.45	0.29	0.00	0.79	0.38	0.00	0.39	0.57	0.00
Intentional 11	0.51	0.29	0.00	0.45	0.43	1.00	0.62	0.63	0.00	0.53	0.57	1.00
Intentional 12	0.49	0.14	0.00	0.31	0.29	0.00	0.45	0.63	1.00	0.44	0.57	0.00
Intentional 13	0.51	0.57	0.00	0.33	0.29	0.00	0.73	0.63	0.00	0.35	0.57	0.00
Intentional 14	0.54	0.57	0.00	0.45	0.57	0.00	0.80	0.75	1.00	0.50	0.71	0.00
Intentional 15	0.27	0.43	0.00	0.17	0.29	0.00	0.81	0.75	0.00	0.54	0.57	0.00
Intentional 16	0.27	0.43	0.00	0.05	0.29	0.00	0.88	0.63	1.00	0.69	0.71	0.00
Intentional 17	0.78	0.71	1.00	0.73	0.71	1.00	0.38	0.75	1.00	0.64	0.71	1.00
Intentional 18	0.76	0.57	1.00	0.72	0.71	1.00	0.60	0.38	1.00	0.38	0.43	1.00
Intentional 19	0.51	0.57	0.00	0.33	0.29	0.00	0.58	0.75	1.00	0.50	0.57	0.00
Intentional	0.54	0.57	1.00	0.33	0.43	0.	0.80	0.63	1.00	0.49	0.57	0.00

20						00						
Random 1	0.27	0.43	0.00	0.05	0.29	0.00	0.30	0.38	0.00	0.27	0.29	1.00
Random 2	0.49	0.57	0.00	0.23	0.29	0.00	0.41	0.38	0.00	0.40	0.43	1.00
Random 3	0.27	0.43	0.00	0.05	0.14	0.00	0.02	0.13	0.00	0.10	0.14	1.00
Random 4	0.27	0.43	0.00	0.05	0.14	0.00	0.14	0.25	0.00	0.18	0.29	1.00
Random 5	0.51	0.43	0.00	0.33	0.29	0.00	0.13	0.13	1.00	0.25	0.29	1.00
Random 6	0.49	0.43	0.00	0.19	0.14	0.00	0.02	0.13	0.00	0.17	0.14	1.00
Random 7	0.76	0.57	1.00	0.47	0.57	1.00	0.43	0.50	1.00	0.55	0.57	1.00
Random 8	0.49	0.43	0.00	0.19	0.14	0.00	0.02	0.13	0.00	0.17	0.14	1.00
Random 9	0.49	0.29	0.00	0.31	0.29	0.00	0.37	0.50	0.00	0.38	0.43	1.00
Random 10	0.51	0.71	1.00	0.69	0.71	1.00	0.44	0.63	0.00	0.42	0.57	0.00
Random 11	0.27	0.43	0.00	0.05	0.14	0.00	0.02	0.13	0.00	0.10	0.14	1.00
Random 12	0.76	0.86	1.00	0.83	0.86	1.00	0.44	0.63	0.00	0.63	0.71	1.00
Random 13	0.73	0.43	0.00	0.59	0.43	0.00	0.69	0.50	1.00	0.63	0.57	0.00
Random 14	0.49	0.43	0.00	0.19	0.14	0.00	0.02	0.13	0.00	0.24	0.14	1.00
Random 15	0.27	0.29	0.00	0.17	0.14	0.00	0.32	0.25	0.00	0.28	0.29	1.00
Random 16	0.49	0.43	0.00	0.19	0.14	0.00	0.02	0.13	0.00	0.17	0.14	1.00
Random 17	0.27	0.29	0.00	0.05	0.29	0.00	0.38	0.38	0.00	0.31	0.29	1.00
Random 18	0.27	0.29	0.00	0.05	0.29	0.00	0.30	0.50	0.00	0.34	0.43	1.00
Random 19	0.27	0.43	0.00	0.05	0.14	0.00	0.02	0.13	0.00	0.10	0.14	1.00
Random 20	0.22	0.43	0.00	0.40	0.57	0.00	0.73	0.13	0.00	0.48	0.57	1.00

The table shows that at face value, the random forest classification of post-mining landscape classifications (identified from literature) values were more likely to be closest to 1 (11/20). However, closer observation shows while there were fewer locations with a value of 1 sampled from the fuzzy and weighted overlay generated maps, these maps also presented the least locations where values were "0" than the random forest classification. The weighted overlay values for the post-mining landscape characteristics maps are below 0.25 (within 0-25%), while the fuzzy overlay version has none. The table also shows that similarly to the post-mining landscape characteristics map generated from literature, 14/20 of the intentional points were closer to 1 in the random classification map. Again, the fuzzy and weighted overlay maps showed that none of the selected values equated to '0', compared to the random classification, where the e value was '0' at six intentional points.

A look at the values extracted from intentional points on the post-mining and urban landscape characteristics maps shows that similarly to the post-mining maps, the random forest classification has 15/20 points where the intentional points returned a value of ‘1’, which is higher compared to the values obtained from the fuzzy and weighted overlay maps. Although the fuzzy and weighted overlay maps present the same pattern observed in the post-mining landscape characteristics maps, none of the points returned a value of ‘1’. It is also interesting to note that the values observed from the intentional and random points extracted from the maps of the urban landscapes are higher than those observed for the post-mining landscape characteristics maps generated using fuzzy and weighted overlay mapping methods.

6.4.3. Landscape characteristics areal coverage per mapping model

The three mapping techniques applied to mapping Gauteng's post-mining and urban landscape characteristics were also validated by evaluating the proportion of values from each model output, fitting urban and post-mining characteristics identified in the literature and from experts. Table 27 presents the total area and proportion of the total area covered by values greater than 25%, 50% and 75% of the total value (1).

Table 27: Areal coverage at 25, 50 and 75% of the Gauteng land area across all three mapping methods.

Results	**POST-MINING CHARACTERISTICS (LITERATURE)**			**POST-MINING CHARACTERISTICS (EXPERTS)**			**URBAN CHARACTERISTICS (LITERATURE)**			**URBAN CHARACTERISTICS (EXPERTS)**		
	Fuzzy Overlay	Weighted overlay	Random forest	Fuzzy Overlay	Weighted overlay	Random forest	Fuzzy Overlay	Weighted overlay	Random forest	Fuzzy Overlay	Weighted overlay	Random forest
Total Area (km2) > 25% Value	17845.47	17730.25	2258.25	6953.94	11486.68	5188.65	12398.32	11036.01	4145.98	10985.18	14783.05	4440.39
Percentage Area > 25% Value	98.18	97.55	12.42	38.26	63.20	28.55	68.21	60.72	22.81	60.44	81.33	24.43
Total Area (km2) > 50% Value	4029.16	3278.49	2258.25	1858.63	3256.57	5188.65	4725.70	2644.05	4145.98	2799.84	3513.58	4440.39
Percentage Area > 50% Value	22.17	18.04	12.42	10.23	17.92	28.55	26.00	14.55	22.81	15.40	19.33	24.43
	772.36	128.59	2258.25	305.82	272.11	5188.65	305.82	60.68	4145.98	305.82	99.11	4440.39

Total Area (km2) > 75% Value												
Percentage Area > 75% Value	4.25	0.71	12.42	1.68	1.50	28.55	9.45	0.33	22.81	1.31	0.55	24.43
Minimum Value	0.03	0.14	0.00	0.03	0.14	0.00	0.02	0.13	0.00	0.10	0.14	0.00
Maximum Value	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Standard Deviation	0.24	0.21	0.25	0.24	0.21	0.25	0.25	0.22	0.25	0.23	0.21	0.25

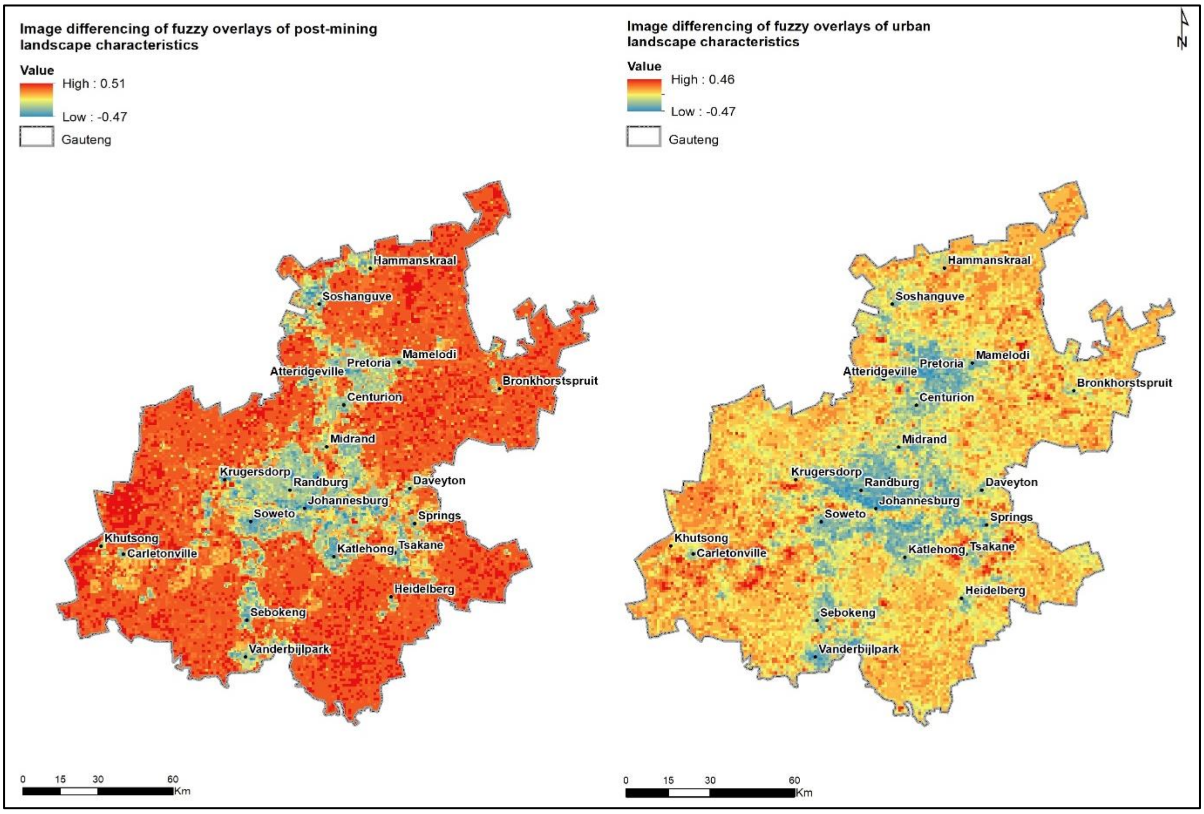
The table shows that when considering the area covered by 25% of the highest value on the map result of post-mining landscape characteristics (identified from literature), the fuzzy overlay has the most areal coverage at 98%, followed by the weighted overlay. By contrast, weighted overlay has the highest areal coverage compared to fuzzy overlay and random forest classification for the maps showing post-mining landscape classification as identified from local experts at 63% of the Gauteng area. The same pattern is also observable with the urban landscape characteristics maps (identified from the literature and experts), where the fuzzy overlay (60%) has the most areal coverage at first. However, it is overtaken by weighted overlay (68%) when looking at the values of the urban landscapes map where the landscape characteristics were derived from local experts. This pattern is the same when looking at the values covering 50% of Gauteng, except when considering the values extracted from the urban landscape characteristics (identified from local experts) map, where instead of the weighted overlay (19%) surpassing the fuzzy overlay areal coverage (15%), the random forest classification (24%) returns the most areal coverage. However, there is a change when looking at the values covering 75% of post-mining and urban landscape characteristics. The fuzzy overlay has the highest areal coverage for the post-mining landscape characteristics identified from the literature (4%); however, random forest classification has the highest areal coverage (28%) for post-mining landscape characteristics from local experts. Furthermore, the Random forest classification has the highest areal coverage for urban landscape characteristics identified from the literature (22%) and local experts (24%). Noting here that the areal coverage of the random forest classification remains the same at all the 25, 50 and 75% areal coverage ranges.

6.4.4. Image differencing of post-mining and urban landscape characteristics

The third validation measure for evaluating the mapped integration of post-mining and urban landscape characteristics entailed a change detection analysis, which entailed image differencing. The image differencing results are divided into three sub-sections for each applied mapping method below: *6.4.4.1.Image differencing of fuzzy overlay of post-mining landscape and urban landscape* *characteristic, 6.4.4.2. Image differencing of weighted overlay of post-mining and urban landscape characteristics* and *6.4.4.3. Image differencing of the random forest classification of post-mining and urban landscape characteristics*.

6.4.4.1. Image differencing of weighted overlay of post-mining landscape and urban landscape characteristics

First, Map 19 shows the image differencing results between the two post-mining landscape maps on the left. Areas with a big difference in the fuzzy membership values between the two maps are indicated in high (red, with values up to 0.51) and low (blue, with values closer to -0.47). In contrast, areas with minimal differences between the values at the same location on both maps are indicated in shades of yellow and have values closer to "0". Areas in shades of yellow would have been presented in similar values in the maps of characteristics identified from the literature and local experts.

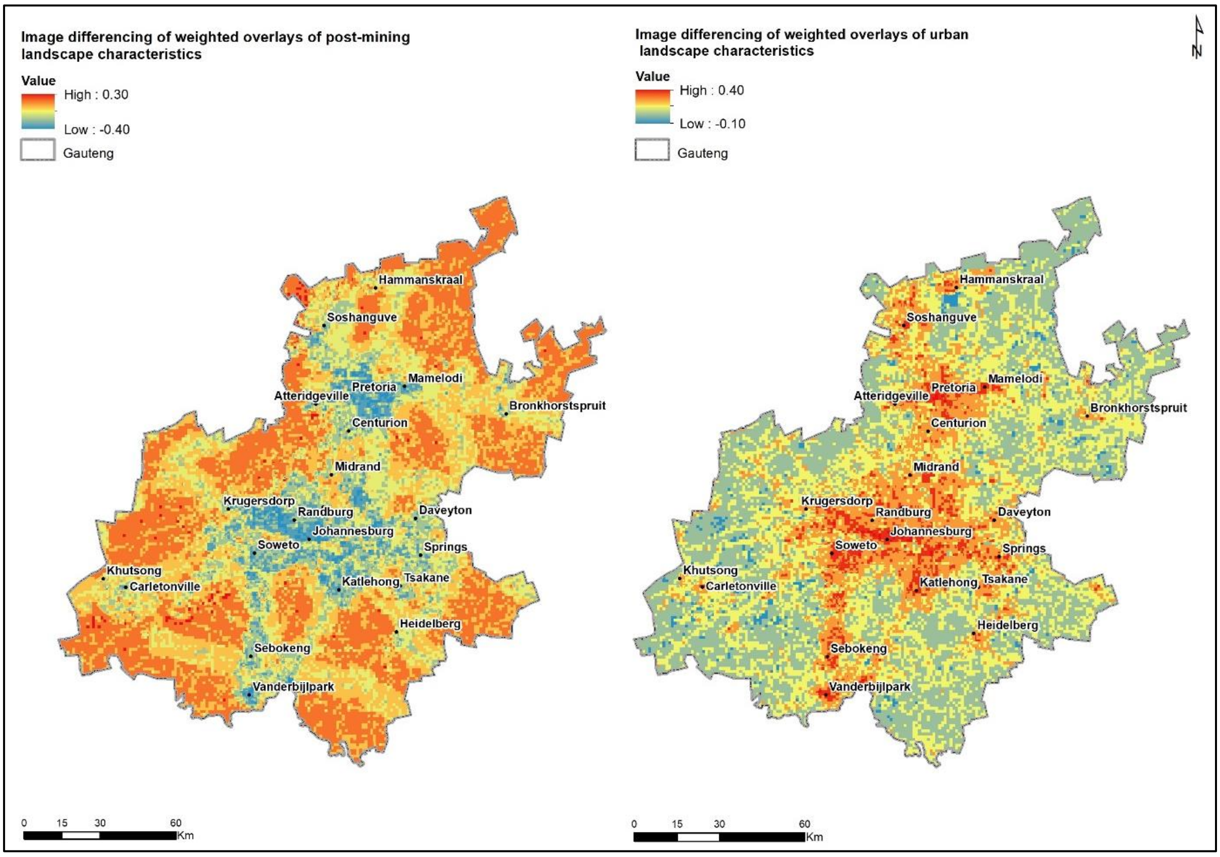


Map 19: Image differencing of post-mining (left) and urban (right) landscape characteristics from literature and experts.

The image differencing results of the two urban landscape maps show that most differences are concentrated at the core and some parts of the province. For instance, the southwestern parts near Carletonville, with differences up to 0.47 either way, indicate the most significant difference in mapping the post-mining and urban landscape characteristics in the maps. This occurs west of Mamelodi and Hammanskraal, north of Carletonville and Khutsong, Soweto, Centurion, Katlehong and Mamelodi. The least differences in fuzzy values are observed mainly at the periphery of the province, although also visible in some parts of the core. In addition, the mining belt traversing across the province is marked by more significant differences in the values between the two maps, indicated by the blue just above Soweto.

6.4.4.2. Image differencing of weighted overlay of post-mining landscape and urban landscape characteristics

The results of the image differencing of the weighted overlay of the post-mining landscape characteristics are shown in Map 20. The map shows that most differences between the two maps are prevalent at the core and the edges of the province, with these areas having a difference of up to 0.30 in either direction. These differences are predominant in Randburg, Soweto, Pretoria, Vanderbijlpark, Diepsloot and Krugersdorp (west of Soweto). By contrast, areas such as the mining belt (north of Soweto) showed minimal differences between the maps.



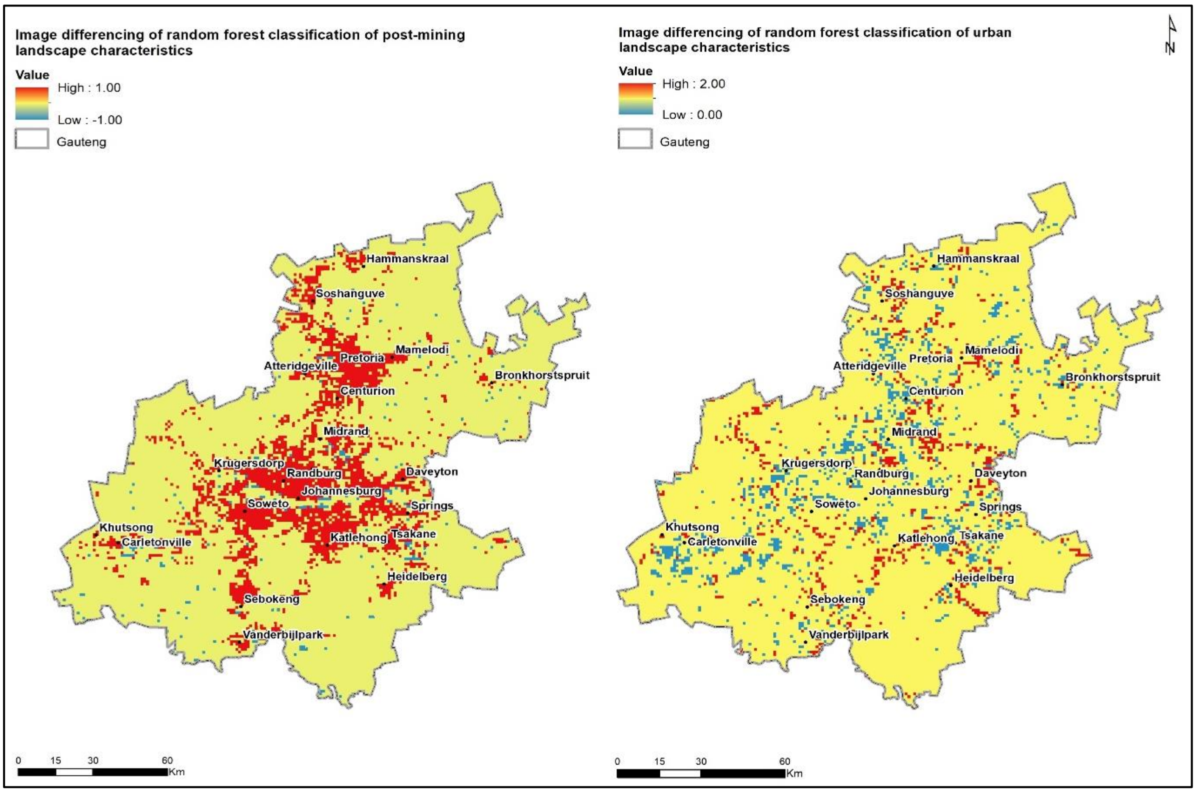
Map 20: Image differencing of weighted overlay of post-mining (left) and urban (right) landscape characteristics from literature and experts.

On the other hand, the image differencing results of the maps of the urban landscape characteristics are presented on the map on the right. The map shows that most differences (where the difference in values can go up to 0.40) between the two maps are prevalent around the core of the province, in areas around Soweto, Alexandra, and along the mining belt, which are marked by high to low values in both maps.

By contrast, areas at the province's periphery indicate lower differences in values and less difference between the two maps.

6.4.4.3. Image differencing of random forest classification of post-mining and urban landscape characteristics

The results of the image differencing of the random forest classification maps of the post-mining landscape characteristics (Map 21) show that most changes between the two maps are prevalent at the core of the province (around areas such as Soweto, Alexandra, Heidelberg and east of Atteridgeville). These areas are marked as having no post-mining characteristics in the map generated from characteristics identified in the literature. By contrast, areas at the periphery of the province show very low-value changes, and these areas were already characterised by low or no post-mining characteristics in previous maps. In contrast, some areas cutting across the mining belt show low to medium changes in the map values as they were already identified as having post-mining landscape characteristics on both maps on post-mining landscape characteristics identified from literature and experts.



Map 21: Image differencing of random forest classification of post-mining (left) and urban (right) landscape characteristics from literature and experts.

The map on the right presents an image differencing of the urban landscape characteristics maps. The map shows few differences between the predictions of urban characteristics values in areas such as Carletonville and Krugersdorp (to the left of Soweto). This can be attributed to the same values across both maps. By contrast, there are big differences between the two maps indicated in red across the province in areas such as those around Hammanskraal and south of Heidelberg.

6.5. SUMMARY OF THE CHAPTER

This chapter outlined the key characteristics of Gauteng's post-mining and urban landscapes. It also has presented how these landscapes can be visualised in an integrated manner, resulting in the required input for developing an integrated framework. The chapter started by presenting the literature and content analysis findings. This was followed by analysing survey questionnaire data from local experts for more contextual descriptions of Gauteng's post-mining and urban landscape characteristics. Some differences were visible at this stage between the general characteristics of these landscapes characterised by the literature and local experts. The identified characteristics outlined a framework for integrating post-mining and urban landscape characteristics. The chapter then demonstrated how the abovementioned framework could be mapped by presenting the results of three mapping methods. The findings from the mapping indicated that the mapping of both the post-mining and urban landscape characteristics differ based on whether the mapping is of only the general characteristics identified from literature or those identified from local experts. The chapter ended with validating the framework by evaluating the results generated from the three mapping methods applied. The results from the validation indicated that the three mapping methods also had an impact on how the landscape characteristics were mapped. This was seen with the areal coverage of both landscapes returned from each map. The image differencing shows spatial differences when considering these landscapes based on the general literature or contextual information. The results from the mapping and the validation of the proposed framework are further discussed in the next chapter.

CHAPTER SEVEN: DISCUSSION OF RESULTS AND FRAMEWORK DEVELOPMENT

7.1. INTRODUCTION

This chapter discusses the research findings from the analysis conducted and presented in *Chapter 6: Analysis of landscape characteristics – A Case Study of Gauteng.* The chapter is divided into three parts. The first part discusses the content and questionnaire analysis findings to identify key characteristics of both landscapes and relate them to the consulted literature. The second part introduces the proposed framework and discusses the spatial representation and validation of the integration of post-mining and urban characteristics. The third part summarises the findings and discusses the applications and limitations of the proposed framework.

7.2. KEY CHARACTERISTICS OF POST-MINING AND URBAN LANDSCAPES

The key characteristics of these two landscapes were identified from the literature and archival material (such as legislation and policy documents) to develop a holistic picture of Gauteng's post-mining and urban landscape. Additionally, local experts, such as academics, consultants and government officials working within related fields or familiar with the Gauteng landscape, completed an online survey for contextual input. The findings from the desktop analysis and questionnaire responses were used to identify the most prevalent post-mining and urban landscape characteristics. Characteristics identified from the desktop-based literature survey were general definitions or characterisations of post-mining and urban landscapes. In comparison, the responses from the local experts were more contextual.

7.2.1. Findings from content analysis of literature and archival material

Reviewing the multi-disciplinary literature and archival material (historical maps, legal documents, metadata documents and policies) on post--mining and urban landscape characteristics yielded interesting results. According to this review, the characterisations of these two landscapes indicate that these landscapes are an agglomeration of different characteristics and are constantly changing or being transformed. Additionally, the review suggests that the characteristics used to describe both landscapes are often at opposing extremes and appear conflicting. Brabyn (1996) argues that conflicting characteristics pose a developmental problem.

The review of post-mining landscape characteristics shows that they are mostly standard and similar across many readings, with most mainly referring to the environmental impact of post-mining and post-extractive industries. For example, they focus on natural resource exploitation and pollution, such as mine dumps, acid mine drainage, tailings, and slimes. These characterisations mainly describe post-mining landscapes as not only being unnatural, incompatible, and needing rehabilitation, as noted by Sklenicka and Kasparova (2008), Svobodova (2012), and Kivinen et al. (2018). Seventeen per cent of characterisations of post-mining landscapes relate to the effects of mining and its resultant waste on the surrounding communities and the conflicts culminating from disproportionate costs and risks of exposure to mine waste and financial gains. This is an important consideration as the social impact of ceasing mining and industrial activities is not commonly reported (Marais, 2013).

Additionally, some 11% of descriptions of post-mining activity related mainly to the economic development that mining brings, but also how mining creates dependencies, especially where mining towns or communities fail to develop and diversify their economies beyond the present mining activity. Only 2% of characterisations of the post-mining landscapes describe these landscapes as assemblages comprising a mix of characteristics and wide-ranging interrelatedness or in terms of the population changes that come with mining. While active, mining attracts labour, which leaves when mines are in the process of downscaling and eventual closure.

The characterisations of the urban landscape seemed to differ across readings noted in different studies such as McHarg and Mumford (1969), Hough (1983) and Brenner et al. (2011). This could be because this concept was developed earlier and has undergone a few paradigm shifts since its introduction (Brenner et al., 2011). Most descriptions (20%) of urban landscapes are related to economic development and opportunities. Brenner (2009), Hough (1983) and Hough (1983) also associate economic development with the urban landscape. Other urban landscape characteristics speak to the diversity of urban processes, society, and governance-related issues (Qadeer, 1981; Rogerson et al., 2014). Moreover, urban landscapes focus on the changes that come with urbanisation and the unprecedented expansion and sprawl of urban areas.

Seven per cent of keywords used in describing urban landscapes related more to density, be it population density or building density. According to several studies (Qadeer, 1981; Hough, 1983; Rickards et al., 2010), urban landscapes are also characterised by accessibility. Three per cent of urban landscape characteristics from this review were related to accessibility to a wide range of services. Additionally, 14% of the identified characteristics of urban landscapes are associated with the use of resources and the resultant pollution from urban processes. In comparison, only 3% are related to the artificial and man-made nature of urban landscapes.

Broadly, these literature findings describe two distinct landscapes. In most cases, these landscapes are characterised using the same characteristic, although at polar opposite ends. Where one is desirable and the other less so. For example, this is seen in the post-mining landscapes characterised as waste or visually incompatible, economic decline and collapse, population changes, isolation, etc. (Berger, 2006; Lorandelle and Haase, 2012), while urban landscapes are often seen as desirable and accessible. Where urban landscapes are associated with density, economic growth and diversity (Qadeer, 1981; Hough, 1983; Rickards et al., 2010), these characterisations would, therefore, be suitable in regions not characterised by post-mining and urban landscapes, such as Gauteng and other regions of mineralised urbanisation. Therefore, the literature findings fall short of providing characterisations that are more encompassing of the other landscape.

7.2.2. Questionnaire evaluation and feedback from local experts: context-specific conceptualisations of urban and post-mining characteristics

Following the evaluation of the characterisation of post-mining and urban landscapes in literature, data was collected from local experts in related fields and professions through a Google Forms survey (and interviews covering the same content as the survey). The data were analysed using frequencies and percentages of responses to determine how post-mining and urban landscapes were characterised and conceptualised by local experts familiar with the Gauteng landscape.

Broadly, this analysis shows that the characteristics of these landscapes are generally similar to those found in the literature, save for a few additional characteristics. Figure 16 (in Chapter 6) shows that according to the local experts consulted, post-mining landscapes are characterised by several new characteristics not previously identified in the literature. For example, post-mining landscapes are characterised by high population densities, unlike population decline, as some literature (Marias, 2013; Harfst, 2015; Nortjie et al., 2019; Marot and Harfst, 2020) suggests. Several responses also related to land ownership issues, an essential aspect of South Africa's apartheid history (Harisson and Zack, 2012; Marais and De Lange, 2021), and other responses related to infrastructural development, including transportation and residential development. According to Mabin (2013) and Harrison and Zack (2012), mining activities are largely responsible for infrastructural development in Gauteng. Interestingly, some other responses related to post-mining landscapes were characterised by small holdings and agriculture, bearing in mind that the Gauteng province was primarily an agro-pastoral region before the discovery of gold.

Similarly, the analysis of the characteristics of the urban, as presented in Figure 17 (Chapter 6), shows that according to local experts, urban landscapes in Gauteng were also characterised by several other additional characteristics. Many studies suggest that European definitions cannot be used to accurately describe urbanism in African countries as these countries are undergoing secondary urbanism (Bryceson and MacKinnon, 2012). Moreover, the definition of an urban landscape in the South African context is a special case because of the inherited apartheid spatial planning legacy. For example, some responses related to fragmentation, referencing urban sprawl and inaccessibility caused by the location of mine waste. Another exciting addition to the characterisation of urban landscapes, and related to mining activities, is mine waste and contamination and post-mining land uses, characteristics that had not been considered in the literature.

Additionally, most local experts reported that their definitions and characterisations of these landscapes stem from literature. This finding indicates that literature, archival material, and mapping are significant in conceptualising the Gauteng landscape as characterised by distinct post-mining and urban landscapes. These experts agreed that literature and other archival material primarily influenced their conceptualisations of these landscapes and their characteristics. However, it is also suggested that these two landscapes are not that distinct after all and their current conceptualisations and characterisations are not adequate for contextual characterisations of these landscapes. Respondents identified data missing from the definitions, conceptualisations and mapping of Gauteng's urban, mining and post-mining landscapes, mostly not included in the literature. This highlights the uniqueness of Gauteng's urban and post-mining landscapes and the Gauteng landscape. As such, this exercise identified the following research gaps: the need for more contextual characterisations of Gauteng's urban and post-mining landscape. The contextual characterisation of urban and post-mining landscapes would also be more integrative of Gauteng's urban and post-mining landscape characteristics.

7.2.3. Post-mining and urban landscapes as assemblages

A comparison of the characteristics of both landscapes identifies similarities and differences used to describe the two landscapes and their characterisations in relation to assemblage theory. Table 28 below shows the collapsed characteristics associated with each landscape, the shared characteristics between the two landscapes and the distinct characteristics between the two landscapes.

Table 28: Comparison between post-mining and urban landscape characteristics identified from the literature and experts.

CHARACTERISTICS			
LANDSCAPE	**CHARACTERISTICS**	**SHARED CHARACTERISTICS**	**CHARACTERISTICS SPECIFIC TO LANDSCAPE**
Post-mining landscapes	Artificial, Assemblage, Economic decline, Integrative rehabilitation and management, Social impacts justice, Population changes, Inaccessibility and isolation, Abandoned infrastructure Natural resource use and degradation, and Transformation	Artificial, Assemblage, Social impacts and conflict, Natural resource use and degradation	Inaccessibility and isolation, Integrative rehabilitation and management
Urban landscapes	Artificial, Assemblage, Density, Natural resource use and degradation, Social impacts and conflict, Economic development and opportunities, Transformation, and Mobility and mutual accessibility		Mobility and mutual accessibility, Economic development and opportunities

Table 28 shows several similar concepts associated with post-mining and urban landscapes. First, similar to assemblages which are comprised of many heterogeneous parts (De Landa, 2005; Dovey, 2010; Kamalipour and Peimani, 2015; Brown, 2020), it can be argued that these landscapes comprise many characteristics, and therefore many parts and are assemblages in their own right. Post-mining landscapes are defined by the arrangement of patches with varying shapes and sizes. These landscapes are heterogeneous and characterised by features such as waste rock, overburden, overburden surfaces, subsided lands, tailings dams, abandoned built and unbuilt spaces and fragments of abandoned spaces that need to be integrated into the urban fabric (Furlan, 2019; Wende et al., 2017; and CSIR, 2019). Urban landscapes are also heterogeneous, comprising a variety of natural and man-made characteristics (Lindholm, 2012), which are spatially organised (Xing and Meng, 2020). These findings are visible in the characteristics from the literature and those identified from local experts for both landscapes.

Second, Table 28 also shows that both landscapes are unnatural, resulting from natural processes, human activity, and, therefore, artificial (Kivinen, 2007; Zhang, 2014; Harfst, 2015; Marot and Harfst, 2020). Local experts (4%) also raised the issue of the post-mining and urban landscapes being artificial. Third, these landscapes are described as complex and transformative, as are assemblages (Brenner, 2013; McGowan, 2019; Roymans et al., 2009; Marcucci, 2000 in Watson, 2020). They transform the landscape from a natural state to a human-made space, affecting their surroundings. Again, this characteristic of post-mining and urban landscapes was also reported by local experts (16% of experts identified this characteristic for post-mining landscapes, compared to 4% for urban landscapes). Fourth, like assemblages, which are multi-scalar (De Landa, 2005; Lindholm, 2012; Kamalipour and Peimani, 2015), post-mining and urban landscapes have impacts that vary in spatial and temporal terms.

Moreover, both landscapes entail activities regionally but with broader relations. In the case of post-mining landscapes, this can be seen with the downscaling and closure of mining activities, which impacts the region's economy, trade and exports. On the other hand, the impervious infrastructure in urban areas may impact local and regional climatic conditions. Fifth, both landscapes hold the potential for economic development and opportunities, albeit in opposing extremes. For example, while post-mining landscapes can also be characterised by economic development and opportunity, it is also characterised by a decline in economic activity and a lack of economic diversity (Brycesson and MacKinnon, 2012). Sixth, another observation from post-mining and urban landscape characteristics is their reliance on natural resources. Mining minerals and urbanisation rely on using natural resources, such as land, and may degrade the natural environment, becoming a development challenge. This characteristic was also identified in expert responses for both landscapes. Another similarity is that a host of societal issues accompanies both landscapes. Social impacts and conflicts emanating from mining or post-mining and urban processes were identified in both the literature and from local expert responses. Seventeen per cent of local experts reported social impacts as a characteristic of post-mining landscapes, while 2% identified it for urban landscapes. For urban landscapes, this was in the form of inequality, social impacts, and disproportionate risk arising from the negative externalities of mining, such as tailings for post-mining landscapes.

However, despite the similarities between these two landscapes, they are also characterised using a host of contrasting characteristics, as shown in column three of Table 28. First, urban landscapes are represented by economic development and opportunities. On the other hand, post-mining landscapes are characterised by both economic growth and decline - growth while actively mining and economic decline with the cessation of mining activity. In contrast, urban landscapes are predominantly characterised by economic growth. Berger (2006) argues that urban landscapes are a direct and physical waste product of post-extractive industries'. However, they can also undergo economic challenges, translating into economic decline and a decline in economic opportunities and diversification. These changes also make assigning weights to such characteristics more difficult. Urban landscapes are also said to be characterised by economic diversity. Urban landscapes are also more accessible in terms of mobility and access to infrastructure and service delivery (Qadeer, 1981; Hough, 1983; Rickards et al., 2010), while post-mining landscapes are primarily isolated and inaccessible, both economically and physically (Mills et al., 2014; Balan, 2020). Other differences can be seen in that post-mining landscapes are often visually distinct (Berger, 2006; Berger and Brown, 2008). They are also seen as hazardous and needing rehabilitation (Lorandelle and Haase, 2012; Kuter, 2013; Limpitlaw and Briel, 2014), while urban landscapes are considered desirable and indicators of development and social well-being. Another difference between the two landscapes is population dynamics. Population changes and decline are associated with post-mining landscapes. First, the population changes come with the introduction of mining activities and in-migration, followed by a decline with the cessation of mining activities (Marais, 2013; Harfst, 2015). By contrast, urban landscapes are characterised by increasing population densities (Hough, 1983; Brenner et al., 2011). Further differences are observed in the investigation of landscape characteristics.

Additionally, the differences observed in the characterisation of these landscapes identified from literature sources versus contextually from local experts demonstrate how assemblages may be spatial and territorial (Deleuze and Guattari, 1987; De Landa, 2005, 2011). However, assemblages, despite their immobility, may also be porous. The porosity of assemblages, such as post-mining and urban landscapes, contextualises various interactions between their components. For example, these landscapes may be destabilised, and this may be visible in the form of struggles for transversal resources, such as water and energy, pollution, the conflict between mining companies and local populations, territorial identity changes and the construction of a mining or urban identity as well as inequalities and environmental justice (Forget and Rossi, 2020). On the other hand, these landscapes are indestructible and in constant recreation, allowing for deterritorialisation and reterritorrialisation. This can be seen in the changes that the Gauteng landscape has experienced, from agro-pastoral to mining and now to a landscape that is primarily urban but also still heavily characterised by mining and post-mining landscapes.

7.3. DISCUSSION OF THE PROPOSED FRAMEWORK FOR THE INTEGRATION OF POST-MINING AND URBAN LANDSCAPE CHARACTERISTICS

Based on the identified characteristics (in Chapter 6) and the discussion above, a GIS framework for integrating post-mining and urban land use characteristics in Gauteng was proposed (Figure 20, in Chapter 6). The proposed framework is envisioned to provide a tangible solution for combining landscape characteristics from seemingly conflicting environments. This section is divided into three parts: first, the framework is introduced, and the integration results based on the framework are discussed. Second, the validation of the proposed framework through an evaluation of mapped results is presented. Third, a discussion on the potential applications and limitations of the proposed framework is presented.

The development process of this framework involved a comprehensive literature review, encompassing studies related to post-mining landscapes, urban land use, and GIS integration approaches. Key concepts and variables were identified, including land cover types, spatial patterns, socioeconomic factors, and environmental indicators. The framework was developed by integrating relevant theories from urban planning, particularly assemblage theory and the field of GIS. Modifications and adaptations were made to existing frameworks to suit the specific research context of Gauteng. These adjustments considered the unique characteristics of the region's post-mining landscapes and urban areas, data availability and technological capabilities. The framework was designed to accommodate diverse data sources, including historical data, satellite imagery, socioeconomic data, and environmental datasets – provided they were in a comparable format and could be further extracted for this framework.

The framework itself consists of three interconnected components:

- The conceptualisation component involves the development of a conceptual model that defines the key landscape characteristics and their relationships (Figures 18 to 20 in Chapter 6). These models serve as a foundation for the subsequent steps in the framework.
- The data component focuses on acquiring, processing, and organising relevant datasets. It includes data collection from various sources, data pre-processing to ensure compatibility and quality, and establishing a geospatial database to store the integrated data. This component also considers data standards and metadata requirements for efficient data sharing and future research use.
- The integration and validation component is the core of the framework, where the integrated datasets are analysed and evaluated. It includes spatial analysis techniques, such as multi-criteria decision analysis, to identify patterns, relationships, and trends within the combined landscape characteristics. The validation process involves comparing the results with ground truth data, conducting accuracy assessments, and iteratively refining the integrated model.

7.3.1. Discussion of mapping and spatial integration of post-mining and urban landscape characteristics

Three mapping methods were used to illustrate the integration of post-mining and urban landscape characteristics, informed by literature and results from a survey with local experts. The results presented in Chapter 6 are discussed below. Each mapping method is discussed separately first, discussing their representation of post-mining and urban landscapes. The representation of these landscapes considering only the characteristics drawn from literature versus those drawn from the survey with local experts is also discussed. This section concludes by discussing the accuracy of these mapping methods and the mapping method most applicable to what this research aims to achieve.

7.3.1.1. Fuzzy overlay analysis of the integration of post-mining and urban landscape characteristics

This section discusses the findings from Chapter 6 (*6.3.3.1. Results of the fuzzy overlay analysis of post-mining and urban landscape characteristics).* First, the characteristics of post-mining and urban landscapes were mapped using a Fuzzy overlay analysis on a scale of 0 to 1. Based on consulted literature (Map 12, left), the results showed high post-mining membership across the mining belt and clusters of high values in areas such as Springs, Krugersdorp and Carletonville. However, low post-mining characteristic membership was observed on either side of the mining belt in areas such as Sandton, Centurion, Pretoria, and Randburg. This suggests that this mapping method recognises these areas' heavy post-mining and mining characteristics.

The results from this map are also similar to how these two landscapes are generally mapped, as most available spatial data and historical maps usually indicate the presence or lack thereof of post-mining areas in these areas. In contrast to existing maps showing mining and urban land uses in Gauteng, this map shows medium values in most parts of the province, especially towards the periphery. These areas are commonly recognised as having mining activity in existing maps of the region. However, this map has identified them as post-mining landscapes because the literature suggests they are not close to transportation but are also characterised by low business, industries and population counts shown in shades of green. On the other hand, the integration of post-mining and urban landscape characteristics, identified from local experts (Map 12, right), presented a different picture of the spatiality of the post-mining landscape, which has not been mapped previously. While high post-mining membership values persisted across the central parts of the province and known mining areas such as Krugersdorp, Carletonville, and Vanderbijlpark, there were also medium to high values on either side of the mining belt, especially at the core of the province.

In contrast to the previous mapping of post-mining landscape characteristics generated from general literature, this map (Map 12, left) shows high post-mining characteristic values in areas associated with the footprint of mining activities, and some areas are typically characterised as urban. This integration of the post-mining and urban landscape characteristics picks up the complexity of the Gauteng landscape, where there is an unclear picture of where the mining activities end and the urban starts and vice versa. The intersections between mining and urban processes have also been noted in studies such as Bobbins and Trangos (2018).

On the other hand, the fuzzy overlay of urban landscape characteristics guided by literature (13, left) shows very high values at the province's core, particularly around Johannesburg, Randburg, and Pretoria. In comparison, there are medium values around the edges of the core and low urban characteristic values at the periphery of the province. It is also interesting to note that low urban characteristic values are picked up in areas associated with mining activity, for example, just above Soweto, where the mining belt is located. Again, this map presented a familiar picture of how urban landscapes are mapped in this region - at the province's core, with fewer urban characteristics further away from the core. By contrast, the fuzzy overlay demonstrating the urban landscape, with characteristics identified from local experts and with added post-mining characteristics (Map 13, right), presented a different picture than the previous map. This map showed high values at the province's core in areas such as Johannesburg, Benoni, Pretoria, Centurion, Carletonville, Sebokeng and Krugersdorp. There is a combination of medium and high values around the edges of the core.

Contrary to the previous fuzzy overlay of urban characteristics map, this map shows more pronounced high values along the mining belt and other known areas of high mining activity. These areas are especially picked up because they align with some urban landscape characteristics, such as increased accessibility, the mining belt close to roads and the railway, mine waste and rehabilitated land[54]. Some urban activities are on previously mined land. Including these areas demonstrates the responses of local experts who included post-mining characteristics.

7.3.1.2. Weighted overlay analysis of post-mining and urban landscape characteristics

The findings from *6.3.3.2. Results of the weighted overlay analysis of post-mining and urban landscape characteristics* present a similar picture to the fuzzy overlay map (Map 12) of post-mining landscape characteristics identified from the literature. The weighted overlay of the post-mining landscape based on characteristics determined from the literature (Map 14, left) exhibited high values across the mining belt and other known areas of mining activity across the province, extending across Springs, Krugersdorp, and Carletonville. Conversely, low values were evident on either side of the mining belt

[54] Several regional studies have argued that mining has had an impact on the urban infrastructural development in the region (Cowey, 1994; Harrison and Zack, 2012; Mabin, 2013). There have also been studies (such as Heath, 2009; Bobbins and Trangos, 2018) highlighting the concern regarding the presence of mine residue and waste in an urban setting such as Gauteng.

in areas such as Sandton, Centurion, Pretoria, Randburg, Krugersdorp, Khutsong, Daveyton, and Heidelberg, as well as all areas marked as within accessible distance to roads and railways. Again, similar to the fuzzy overlay map, this map picks up mining land uses as generally mapped in the area. This map also shows medium values in areas not characterised by post-mining characteristics, particularly areas not close to transportation, with low business, industries and population counts, displayed in shades of green. This map would correctly pick up post-mining areas identified in the literature, as the literature suggests that post-mining landscapes are inaccessible and characterised by declining economies and populations. By contrast, Map 14 (right), identified from local experts, presented a broader coverage of post-mining characteristics still showing high values cutting across the province, where the mining belt is. Clusters of high values across the province also show medium to high values on either side of the mining belt, especially at the province's core. Similar to the previous fuzzy overlay map of post-mining landscape characteristics identified from local experts, this mapping approach identifies areas characterised by the footprint of mining activities and some areas characterised by urban areas as having high post-mining characteristic values. The highest values here are located along the mining belt. While areas on either side of the mining belt are characterised mainly by high populations, high business, high industry counts, and high accessibility, they indicate medium to high post-mining characteristic values.

Regarding the urban landscape characteristics, the weighted overlay analysis of characteristics identified from the literature (Map 15, left) displayed high values at the province's core, particularly around Johannesburg, Randburg, and Pretoria. Medium values were present at the urban edge or fringe, such as the stretch between Alexandra, Centurion, and Carletonville. Low values were observed at the periphery of the province, reflecting areas distanced from economic activity, density, and access routes as literature describes urban landscapes (Qadeer, 1983; Hough, 1983; Brenner et al., 2011; Rogerson et al., 2014). These areas have low values because characterisations of urban landscapes did not include mining activities. By contrast, the weighted overlay map of urban characteristics with the addition of characteristics identified from local experts (Map 15, right) presented high values at the province's core, including pronounced high values, especially along the mining belt. This integration demonstrates the unclear boundary between the two landscapes. These areas are also picked up as they have increased accessibility to roads and the railway, characteristics most associated with urban landscapes. Medium and high values were observed around the areas immediately outside the core. This map is similar to the previous one, although it shows more pronounced high values cutting across the province along the mining belt.

7.3.1.3. Random forest classification of post-mining and urban landscape characteristics

The findings from the random classification of post-mining characteristics[55], identified from the literature (Map 16, left), predicted high post-mining characteristic values across the mining belt, extending to areas such as Springs, Krugersdorp, and Carletonville. However, low post-mining characteristic values were predicted on either side of the mining belt, especially in the north, including areas like Sandton, Centurion, Pretoria, and Randburg. This map predicts mining-related land uses in traditionally mapped mining areas, like the literature-based fuzzy and weighted overlay representations of post-mining characteristics. However, integrating urban characteristics identified from local experts (Map 16, right) presents a more expansive coverage of post-mining characteristics. While still showing high post-mining values, especially at the province's core, the map also identifies high post-mining values in areas characterised by urban landscape characteristics. These findings were similar to fuzzy and weighted overlay maps of post-mining characteristics identified by local experts, suggesting an intersection between characteristics associated with these landscapes. However, in contrast to these other maps, this map is restrictive as it does not consider the lack of a sharp boundary between these two landscapes. Meinig (1979) and Palang (2010) also argue that landscapes are transitional and do not have sharp boundaries.

Regarding urban characteristics identified from the literature, the random forest classification of urban landscape characteristics (Map 17, left) depicted very high values at the province's core, particularly around Johannesburg, Randburg, and Pretoria, predominantly in the north. Patches of low values, for example, near Randburg, north of Soweto, east of Alexandra, and at the periphery of the province, were observed. This map reflected a familiar picture of this region's urban landscape (for example, in Maps 5-7). However, the integration of post-mining characteristics, as identified from local experts (Map 17, right), also shows high values in the core areas, including a larger spatial footprint of high values that incorporated known mining activity areas. This map presents an alternative to the map on the left, as it integrates post-mining characteristics identified by local experts.

The discussion of the results of the three mapping methods employed in this research further suggests differences in the characterisation of these landscapes. The results also showed that the maps generated from the literature-derived characteristics had a slight similarity to existing and traditionally mapped representations of the post-mining and urban landscapes of Gauteng, where the post-mining and urban land uses are mapped as though occupying different spatial units (such as those presented in Maps 5-7). These findings demonstrated the impact of literature on the representation of space. The survey content from local experts also suggests that these maps do not represent all the characteristics

[55] The findings are presented in section *6.3.3.1. Results of the random forest classification of post-mining and urban landscape characteristics*.

associated with these landscapes. These maps, therefore, stand the risk of miscommunicating what exists on the ground with what is on the map. At the same time, these maps demonstrate how the two landscapes lend themselves as assemblages in and of themselves. According to De Landa (2006), assemblages are wholes that form through the interaction of their constituent parts. In this case, post-mining and urban landscapes are created through the combination and interaction of their characteristics.

These maps also demonstrate how the characteristics of these two landscapes intersect on the same spatial unit, which is visible in those areas of high membership or predictive values. These maps change when other information or contextual knowledge and descriptions of the landscape are added, raising questions about understanding the Gauteng landscape. It suggests a more complex relationship between these two landscapes, which cannot simply be drilled down to two separate landscapes. Therefore, integrating post-mining and urban characteristics for the mapping of Gauteng could potentially serve as a tool to inform a more holistic picture and understanding of the province. This would be useful for numerous reasons, such as the complete representation and conceptualisation of the Gauteng landscape.

Additionally, the integration of these landscape characteristics in general and specific points across the Gauteng province also points towards the porosity of the boundaries of these two landscapes. Therefore, these results demonstrate the importance of counter-mapping space, interrogating the representation of space and the technical decision behind maps, as noted by Cattoor (2019). These findings are further elaborated in section *7.3.3. Potential practical applications and conclusions on the proposed framework for integrating post-mining and urban landscape characteristics*.

7.3.2. Validation of the mapping of landscape characteristics based on different mapping techniques

The mapping of the integration of post-mining and urban landscape characteristics was further validated in four ways to understand the results. These results are discussed below in the following order: results of confusion error, results of cross-evaluation, results of areal coverage assessment, and results of the change detection.

7.3.2.1. Discussion of confusion matrix results

The results of the confusion error assessments (Tables 20-25) suggest that the mapped accuracy results are higher in those maps portraying post-mining landscape characteristics identified from literature than experts, except those maps generated using a weighted overlay. These findings are attributable to several factors, such as that these maps mainly picked up post-mining areas, and the reference data validated these. These post-mining landscapes are also close to transportation routes and, therefore, accessible, in contrast to those post-mining landscapes that are not easily accessible. Gauteng's road and rail networks were introduced with the settlement of the Dutch and later expanded to make transporting mined goods easier (Mabin, 2013). Another reason for this is that the locality of post-mining landscapes is quite close to the economic core of the province, which is characterised by economic activity and opportunities, high populations, high employment, etc., which again are not characteristic of post-mining landscapes according to the literature. However, these maps used a default weighting for the weighted overlay maps as values were not easy to apply as most of these characteristics, such as the economic status change and any values, would have been subjective. On the other hand, the accuracy results of the weighted overlay and random forest classification mapping methods for mapping and integrating the urban landscape characteristics show that the mapped accuracy results are higher in those maps mapping urban landscape characteristics identified from experts than in the literature, except those maps generated using a fuzzy overlay. This can be attributed to most of the additional characteristics identified from the literature were already close to urban land uses. On the other hand, the fuzzy overlay map suggests that areas on the map could have membership belonging to both urban and post-mining landscape characteristics, and if this is the case, the reference data would not have picked this up.

7.3.2.2. Discussion of the results of the cross-evaluation of values across the resultant

The sampling of reference and random points across the map results for cross-evaluation (Table 26) further show the differences in the mapping techniques applied to map these landscapes. The random forest classifications are indicated as either post-mining or urban with no in-between. The fuzzy and weighted overlay maps suggest that most areas in Gauteng are at least characterised by some post-mining and urban landscape characteristics, presenting these areas as having low to medium membership and weighted overlay values in the maps. None of the sampled points had a value of "0", as with the random forest classification. This suggests that some parts of the province comprise a mix of landscape characteristics. This could especially be true in those areas that have, for instance, undergone rehabilitation and reworked into the urban frame or in places with post-mining characteristics but also economic development. Essentially, these maps indicate the complexity and mixing of these two landscapes. These two mapping methods are beneficial for picking up even the slightest characteristics that could be identified as post-mining and urban, indicated in areas with low values.

7.3.2.3. Discussion of areal coverage results

The comparison of the total areal extent (in km^2) of post-mining and urban landscapes (Table 27) showed that maps generated from literature-derived characteristics had higher areal coverage than those derived from the local experts. More specifically, however, the fuzzy overlay and weighted overlay mapping techniques tend to show the two landscapes having a larger areal coverage. This finding differs from other mapping techniques that provide straightforward boundaries around spatial features, therefore oversimplifying them. Therefore, these two mapping techniques are good for demonstrating the complexity of landscapes and the mixing of different landscape characteristics. This can be seen, for instance, in the mapping of post-mining landscape characteristics from general literature using a fuzzy and weighted overlay, which shows that when considering the areal coverage based on values over 0.25 (25% of the total land mass), these characteristics cover 98% and 97% of Gauteng’s areal extent. When the same is done for those values over 50% (0.5), the fuzzy overlay and weighted overlay of post-mining characteristics have an areal coverage of 22% and 18%, respectively. On the other hand, when the same is done for characteristics identified from experts, the areal coverage of fuzzy and weighted overlay values over 25% is 38% and 63%, respectively. While at over 50%, the areal coverage is 18% and 26%. This pattern is the same when looking at the values covering 50% of Gauteng, except when considering the values extracted from the urban landscape characteristics (identified from local experts) map, where instead of the weighted overlay (19%) surpassing the fuzzy overlay areal coverage (15%), the random forest classification (24%) returns the most areal coverage. However, there is a change when looking at the values covering 75% of post-mining and urban landscape characteristics. Fuzzy overlay has the highest areal coverage (4%) for the post-mining landscape characteristics identified from the literature, while random forest has the highest 28% for those from local experts. Noting that the areal proportion of Gauteng covered by urban and post-mining characteristics further decreases with the extraction of values greater than 50% and 75%, this is seen in maps generated from fuzzy and weighted overlay analysis only as they are using a gradual scale. By contrast, the random forest classification of the same characteristics shows that only 12% of Gauteng is covered by these characteristics. Similar results can also be seen in mapping post-mining landscape characteristics based on contextual expert input and mapping urban landscapes across all three mapping techniques.

7.3.2.4. Discussion of the image differencing results

The image differencing of the post-mining landscape characteristics across all mapping methods (Maps 19-21) shows that most changes between the two maps (of characteristics identified from literature and experts) are prevalent at the core and periphery of the province. While the differences are mathematically attributable to high and medium values on one map and low values on another, these differences also point to the differences in the characterisation of post-mining characteristics more generally and at a contextual level. It is interesting to note the changes at the province's core as in the context of Gauteng; this area is characterised by economic activity, development, high population densities, transportation routes and accessibility, all of which are characteristics associated with urban landscapes in literature. For example, Berger (2006) states that post-mining landscapes are inaccessible. At the same time, Marais (2013) states that post-mining landscapes are in a state of economic decline. It is also interesting to note the other significant changes at the periphery of the province. While these areas are characterised by medium values across all the maps using characteristics identified from the literature, the inverse is true in those of characteristics from local experts, as low values characterise them. These areas are not easily accessible and have low economic activity and populations – all synonymous with post-mining landscapes in literature (Marais, 2013; Rogerson et al., 2014). By contrast, the map indicates the least difference between the two maps along the mining belt. These are areas that had high membership in both maps.

On the other hand, the image differencing of urban landscape characteristics across all three mapping methods (Maps 19-21) shows that most differences between the two maps are prevalent at the core. These findings were unexpected considering that the province's core was mapped as urban across all three mapping methods and on both the literature and expert-based maps, unlike in the post-mining maps. The image differencing shows that most of the changes from the literature to the expert-generated maps are attributable to increased urban characteristics in the expert-derived maps. Moreover, these maps show high differences in map values along the mining belt and other known areas characterised by mining activity and at the periphery, for example, north of Soweto and in Boksburg (northwest of Springs). This is also attributable to the literature that mostly describes urban areas as away from mining and extraction sites (Berger, 2006). The least differences across the maps are noted at the periphery of the province as both maps had picked up only a few urban characteristics in these areas.

In summary, validating the three mapping methods provided interesting perspectives on the spatial representation of the integration of post-mining and urban landscape characteristics. They are showing that different mapping techniques also have an impact on mapped results. For instance, the weighted and fuzzy overlay maps use a scale range, where any characteristics within each grid cell are considered in the final issuing of membership, rather than the random forest classification, which uses a binary scale. Contrastingly, random forest classification uses a binary classification method, including or excluding landscape characteristics as urban or post-mining. The random forest classification offered a predictive approach but lacked consideration for the unclear boundary between mining and urban areas. The three mapping methods present different accuracy rates for mapping post-mining and urban landscape characteristics. The maps generated from the expert-derived characteristics resulted in mostly lower accuracy scores. However, this is attributable to the inclusion of characteristics not often included in the mapping of these landscapes and the reference data used for the validation. However, for this study, the maps generated from landscape characteristics identified from local experts were also considered to represent the complex relationship between mining and urban landscapes more comprehensively. The fuzzy and weighted overlay analyses emphasised these landscapes' overlapping nature and demonstrated this complexity. However, the fuzzy overlay was considered the most suitable mapping technique for the proposed framework in this study as it considers the fuzzy nature of these landscapes. This is demonstrated by the medium membership values prevalent in areas characterised by multiple characteristics in the literature-derived and expert-derived characteristics maps. The fuzzy overlay maps also had high accuracy scores for both the literature and expert-derived characteristics mapping of post-mining and urban landscapes. Moreover, the applications of fuzzy overlay have been commended in other studies (Brabyn, 1996; Van Eetvelde and Antrop, 2009) for their ability to incorporate expert information.

7.3.3. Potential practical applications and conclusions on the proposed framework for integrating post-mining and urban landscape characteristics

Figure 16 also demonstrates that while the characteristics of these landscapes may be in opposite ends in most contexts and described as such in literature, this is also demonstrated in the mapping of post-mining and urban characteristics identified from the literature. However, as demonstrated in Figures 18 and 19, some regions may comprise characteristics from both landscapes, such as in Gauteng (represented in purple). Quite uniquely, these seemingly contrasting landscapes share the same spatial unit and landscape, contributing to the larger Gauteng landscapes – similar to the many parts comprising assemblages. This shows the importance of contextual characterisations and conceptualisations of landscapes. This is further demonstrated in mapping these landscapes, guided by characterisations identified from the literature and local expert knowledge, which shows how different understandings of a landscape may present different pictures of the same landscape. This is indicated by the spatial variations in mapping both landscapes using the general versus contextual characterisations of the post-mining and urban landscape characteristics.

On the one hand, mapping these landscapes based on characterisations from literature presents a picture similar to what Brabyn (1996) argues are distinct landscapes – this is also how these two landscapes are commonly presented in this region. An observation from this study was that each landscape records the highest or lowest values in areas characterised by characteristics most associated with it without allowing any mixing, showing conflicting landscapes. Mapping from this standpoint limits their integration and co-existence in space. On the other hand, mapping more regional characterisations of these landscapes, using the example of the Gauteng landscape and guided by local expert input, the maps of these two landscapes suggest a level of overlap and spatial co-existence. This suggests that the current mapping of these landscapes as distinct landscapes does not demonstrate the dynamism and complexity of these landscapes, which shows that context matters in the understanding of landscapes.

Based on the above discussions, Figure 21 presents a revision of the conceptualised relationship between post-mining and urban landscapes for integrating Gauteng's post-mining and urban landscape characteristics. Figure 21 is useful for implementing and interpreting the proposed framework. Post-mining landscape characteristics are again presented in red, and urban landscape characteristics are in blue. These two landscapes' sum or integrated view is demonstrated as a maroon layer.

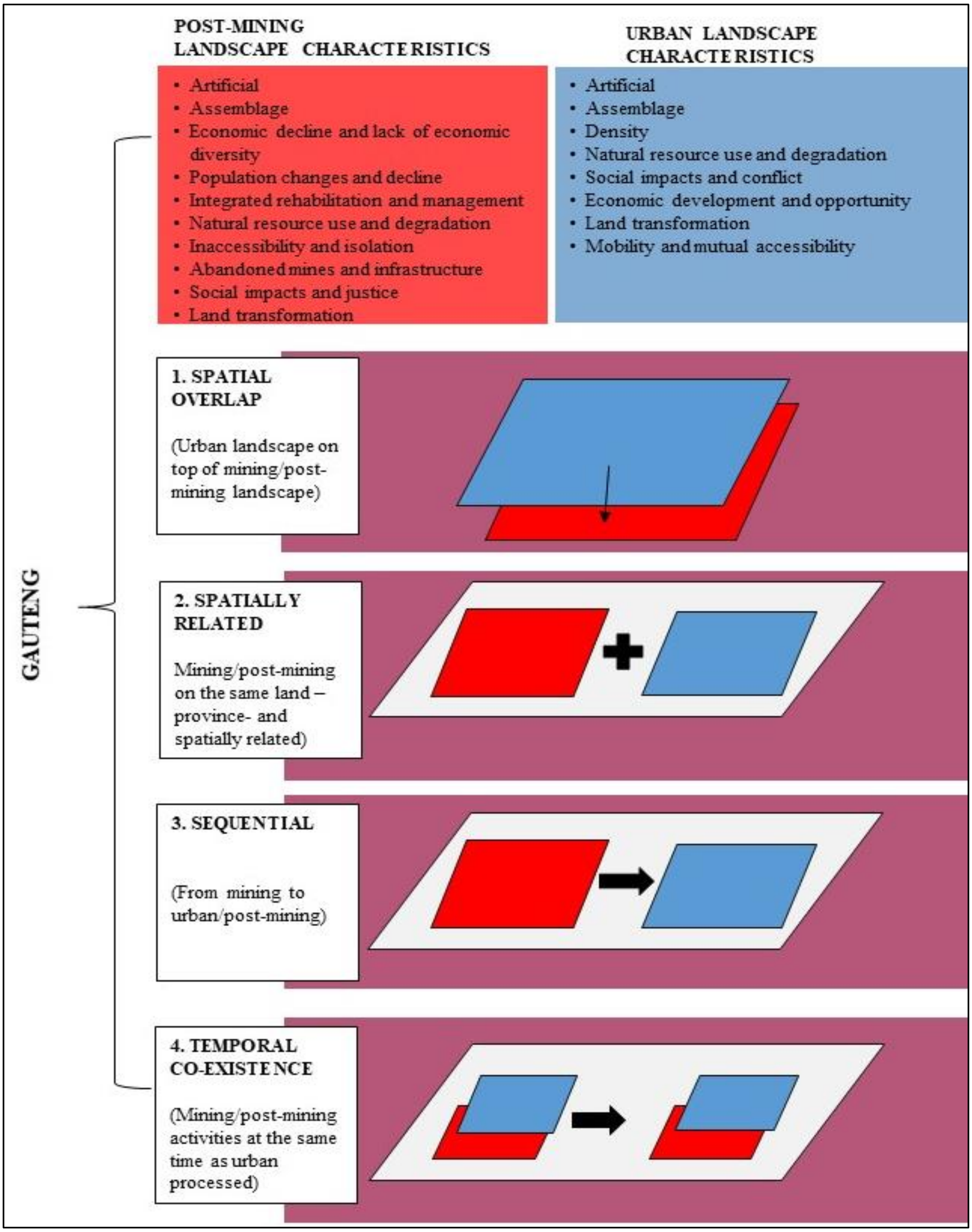


Figure 21: A revision of the proposed conceptual framework for the integration of post-mining and urban landscape characteristics.

First, as proposed by Deleuze and Guattari (1987), who argued that assemblages are rhizomatically interconnected, this framework and the mapping suggest that Gauteng's post-mining and urban landscapes are connected in several ways. For example, Figure 21 proposes that integrating the characteristics of these two landscapes requires a level of understanding that these two landscapes may, in some areas, overlap spatially – therefore suggesting a physical connection between these two landscapes. This may be attributable to several reasons; for example, some mining activities and characteristics occur in the subsurface and are not visible, which means urban processes may occur above them. Figure 22 demonstrates where this may be the case using the example of a mining reef in Luipaardsvlei and the boundaries of mining licenses along the Witwatersrand. The underground workings of Luipaardsvlei and the mining licenses were superimposed with the fuzzy overlay, weighted overlay and random forest classification maps of post-mining and urban landscape characteristics. Another example can be seen in mining-related businesses' presence in urban office parks.

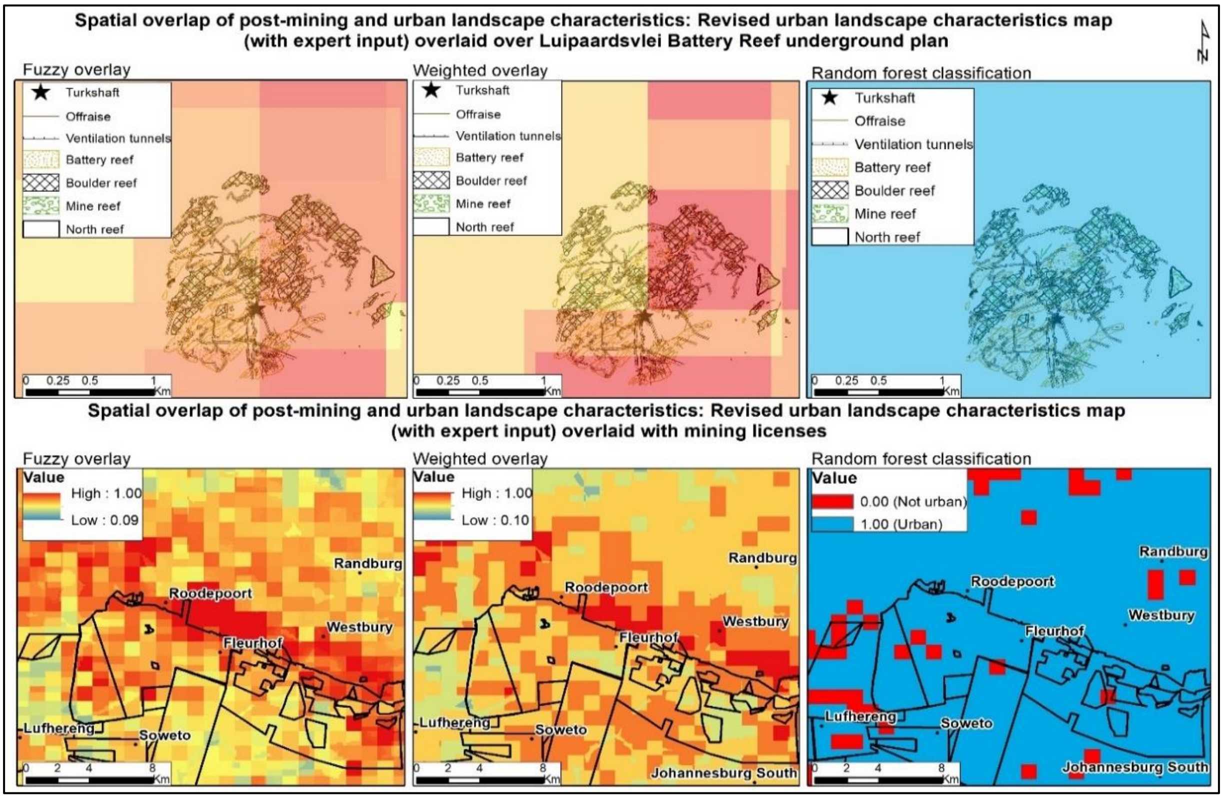


Figure 22: Spatial overlap of post-mining and urban landscape characteristics.

Second, using the proposed GIS framework for integrating post-mining and urban landscape characteristics, it is important to consider that these landscapes overlap in some areas and may be spatially related. An example of what is meant by this is demonstrated in Figure 23, which shows that the maps with characteristics identified from local expert input present high values in some parts of the province, such as Krugersdorp, Roodepoort and Fleurhof. This is the same across all mapping techniques. This is attributable to the concentration of different landscape characteristics on the same land unit, in this case, Gauteng province – noting that the grids used in these maps cover an area of 1 km^2. The area along the Witwatersrand mining belt is another case in which the map shows high values in these areas, and the area is characterised by mining activities (ongoing and discontinued) and urban processes such as informality and infrastructural development from the proximity to road infrastructure. This suggests that the characteristics of the two landscapes are inextricably linked or related to each other. Moreover, landscapes themselves are heterogeneous, comprising different characteristics at different scales and are, in essence, assemblages.

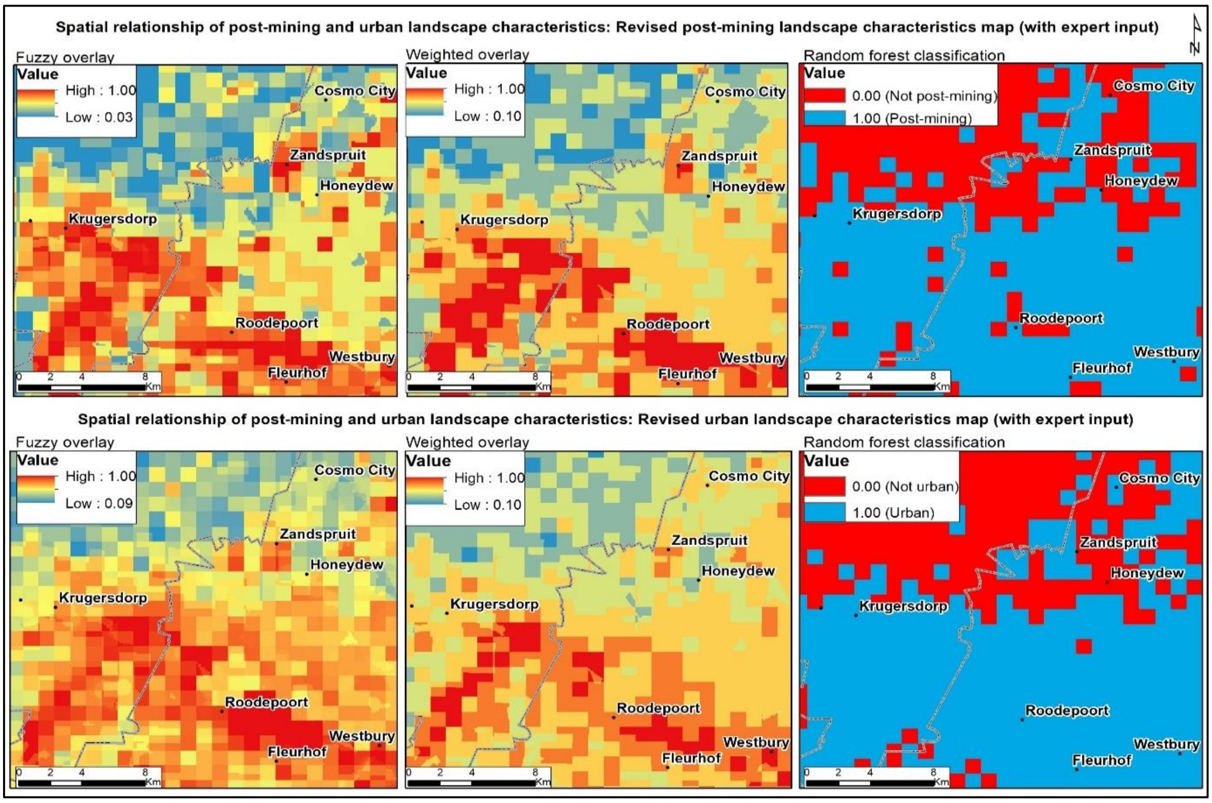


Figure 23: Spatial relationship and concentration of post-mining and urban landscape characteristics.

Third, mapping the two landscapes at a regional scale shows that they may co-exist. In the context of Gauteng, mining activities have continued in this rapidly urbanising province. The mining and urban land use data (1990, used as a proxy for historical data) and mapping of the land use data as of 2020 demonstrated this (Figure 24), especially seen in the membership maps in Chapter 5. Figure 24 on the left shows temporal co-existence around areas such as Carletonville, characterised by mining-related land uses (red), urban-related uses (yellow), and areas with both characteristics in orange 1990. For example, Carletonville is an area heavily characterised by many active and abandoned mining activities with other economic activities. Similarly, Figure 24 (on the left) also shows similar trends in areas, such as the area south of Krugersdorp and Roodepoort, where urban-related uses were yellow, mining-related land uses red, and spaces of co-occurrence orange. On the other hand, Figure 24 on the right shows a similar trend in 2020, where some parts of the province, such as Roodepoort, Krugersdorp and Carletonville, have both mining-related land uses (light red) and urban land use characteristics (yellow) and therefore present as orange.

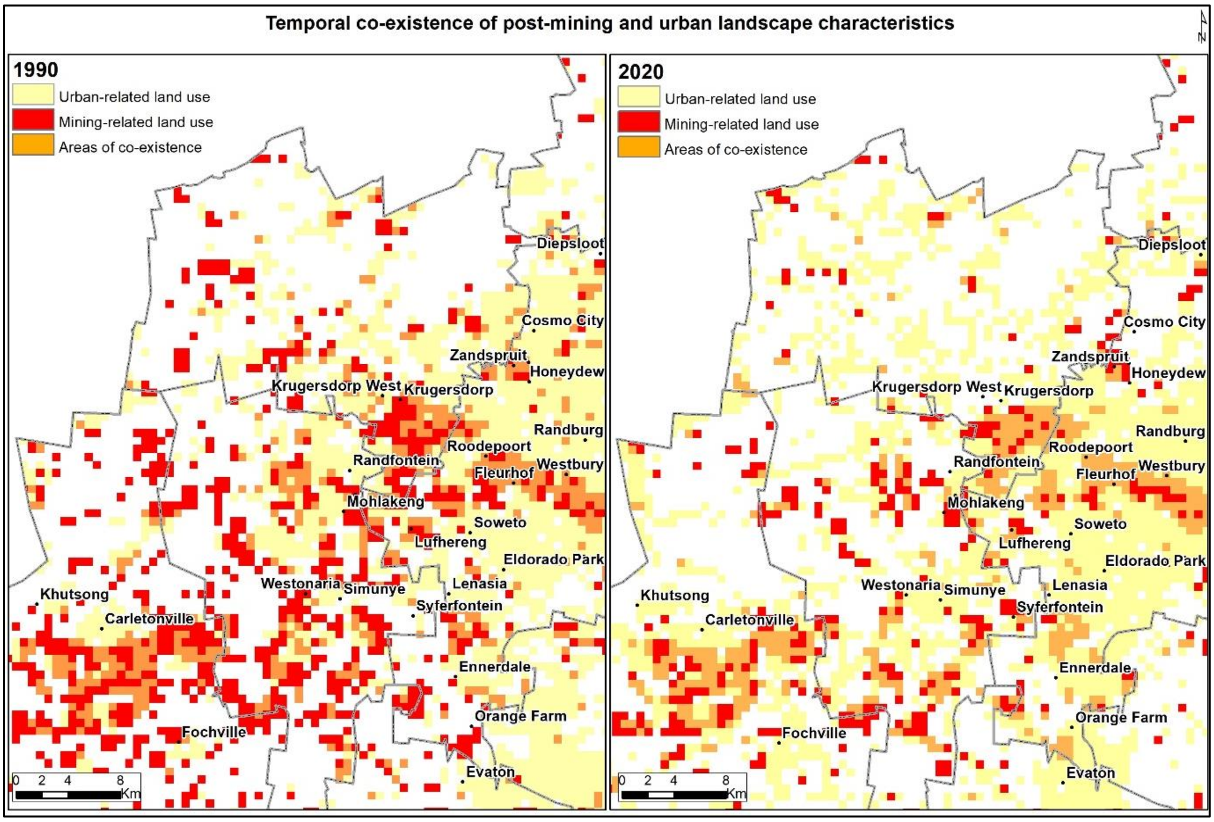


Figure 24: Temporal co-existence of post-mining and urban landscape characteristics.

Fourth, the integration of post-mining and urban characteristics based on the proposed framework suggests that the two landscapes may change over time, as described in studies such as Berger (2006), Meinig (1979) and Palang (2010), which state that post-mining and urban landscapes may vary temporally. Similarly, Wise (2005) and Roymans et al. (2009) also suggests assemblages undergo a reordering and organisation process. The first two maps at the top of Figure 25 indicate that these processes also characterise the Gauteng landscape. This is demonstrated upon closer observation of Figure 25, showing mining and urban-related land uses as of 1990 and 2020 - collapsed at the 1 km^2 grid level. The two maps at the top of Figure 25 show the transformation of mining and urban-related land uses between 1990 and 2020. The map shows that the mining and urban-related land uses have not changed in most areas – these areas are presented in orange, where there is an overlap between mining and urban-related land uses from 1990 and 2020. This can be seen in areas between Roodepoort and Krugersdorp for mining and Soweto, Randburg and Westbury for urban-related land uses. However, the map also shows that there are new areas characterised by mining and urban-related land uses in 2020 (indicated in yellow in both maps), and there are also other areas that had been mining or urban-related land uses in 1990 (shown in red) which are no longer characterised as such in 2020.

Additionally, Klug (2012: 621) also states that such instances indicate a '*temporal multifunctionality'*, referring to the "spatial overlap of functions on the same land unit at successive periods (dynamic)". Similarly, Roymans et al. (2009), Brycesson and MacKinnon (2012) and Klug (2012) also state that two landscapes may exist sequentially on the same spatial land unit. In the Gauteng context, the mining landscapes preceded the urban landscape, developing with the discovery of gold in a largely agro-pastoral environment. The two maps at the bottom of Figure 25 show the change from mining to urban-related land uses and vice versa. The map on the left shows how some mining-related land uses from 1990 (indicated in red) have been converted into urban-related land uses in 2020 (previously indicated in yellow) and are marked in orange. For example, this can be seen south of Krugersdorp and Roodepoort.

Similarly, the map on the right shows how some urban-related land uses from 1990 have been converted into mining-related land uses in 2020 in areas such as Boksburg to the east of Benoni. This shows that, on the one hand, these landscapes are interconnected through their temporal and sequential co-existence, yet on the other hand, these landscapes also demonstrate spatial arrangement. This is shown in maps 12-15 in those parts of the post-mining and urban landscape maps demonstrating low membership values of the other landscape characteristics.

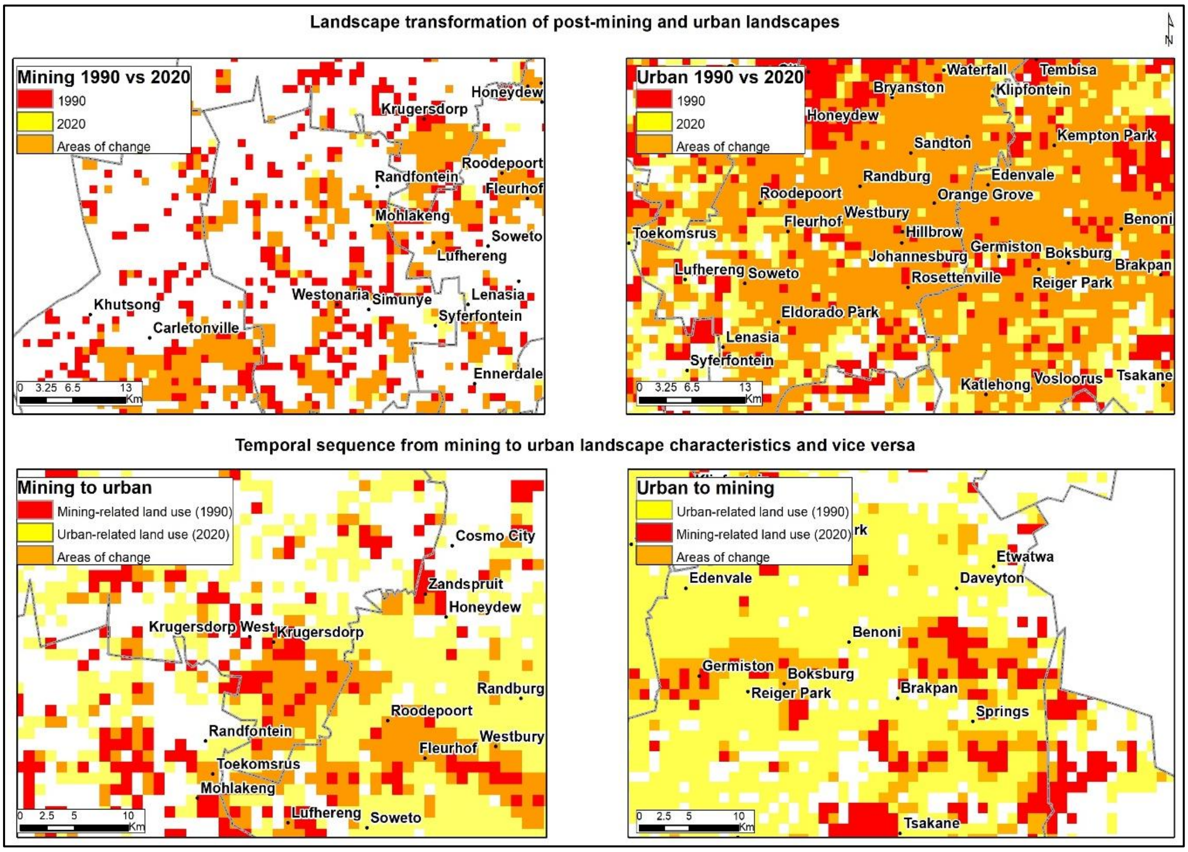


Figure 25: Spatial transformation and temporal sequencing of post-mining and urban landscape characteristics.

A framework for the integration of post-mining and urban landscape characteristics, as presented in Figures 18-21, has the potential to provide many applications in the context of Gauteng: First, it gives insight into the complexity of these two seemingly distinct landscapes, post-mining and urban landscapes, presenting them as comprised of an assemblage of landscape characteristics. Second, the identified post-mining and urban landscape characteristics from literature and experts indicate further differences in how these landscapes are characterised and described in the literature and at a contextual level. These findings are similar to those found in studies such as Bellone (2020), who suggests that the representation of space continues to be that of the West in the present. Moreover, these findings also suggest that space may be ambulatory and relative (Larsen and Beech, 2014).

The integration of these two landscapes and their related characteristics guided by the proposed framework also presents some insight into the complexity of these landscapes. The above-demonstrated integration of these two landscapes suggests that while the Gauteng province no longer relies on mining for economic development, mining activities still play a prominent role in this province's economy and spatial development. In a rapidly urbanising context, such as Gauteng, characterised by a high demand for natural resources,[56] such a framework and integrated view of the Gauteng landscape starts to provide some insight into the relationship between the two landscapes.

Scholars such as Krupar (2015), Desimini and Waldheim (2016), Vaughan (2018), and Alderman et al. (2021) argue that for a long time, maps have been considered objective representations of space, although they are socially constructed. Such a framework as the proposed and integrating post-mining and urban characteristics is also useful for challenging the representation and conceptualisation of these landscapes as distinct (Cattoor, 2019). By providing an alternative representation of these landscapes, not as standalone but as integrated, this research potentially provides insights into new conceptualisations of urban landscapes, post-mining landscapes and mineralised urbanisations. Additionally, as stated by scholars (Brabyn, 1996; Klug, 2005; Ridding et al., 2018; Liu and Nijhaus, 2021), the value of holistic landscape mapping provides decision-makers with a better understanding of how the landscape functions. Additionally, the study of landscape characteristics supports planners in communicating with stakeholders and the public (Liu and Nijhaus, 2021). In the context of Gauteng, such information is valuable for understanding that these two landscapes interact at different scales and extents and, therefore, other areas may also benefit from different management approaches. Thus, the value of this work is also in the conceptualisation of Gauteng as a post-mining urban landscape, although still characterised by some mining activity. Moreover, the significance of this work is also in its mapping of the post-mining and urban landscape in a way that has not been done before, which depicts mining landscapes as covering more than the traditionally mapped areas. This is useful in this context because most of the initial mining in the area was also underground, and the lack of data to show this means that the subsurface post-mining landscape is not incorporated into the mapping of this landscape.

[56] High demand of natural resources for the development of human settlements and a large acreage of land is zoned off and lost to mining and mining waste.

Another contribution of this work is that it contributes to the body of work on the applications of MCDA in urban and post-mining landscapes after several studies (Bielecka and Król-Korczak, 2010; Król-Korczak and Brzychczy, 2019 and Arratia-Solar et al., 2022) have reported the limitation of MCDA studies in post-mining contexts. The high fuzzy membership of post-mining characteristics from experts in areas identified as urban from literature, and the high fuzzy membership of urban landscapes from experts in areas identified as having post-mining landscape characteristics in literature, therefore, suggests that fuzzy overlay may potentially be useful in similar contexts of mineralised urbanisation.

7.3.3.1. Limitations of the proposed framework

Nevertheless, it is important to acknowledge that the proposed integrated mapping of post-mining and urban landscapes faces certain limitations and potential drawbacks. The framework's effectiveness depends on data availability and quality from diverse sources, which may present data acquisition, compatibility, and consistency challenges. This issue has already been noted as hindering a better understanding of how mining and urban processes interact spatially in several studies, such as Bobbins and Trangos (2018) and Watson and Olalde (2019). Another observed challenge in this study was the absence of appropriate reference data encompassing the characteristics of post-mining and urban landscapes derived from literature and local experts. Furthermore, integrating and analysing multiple datasets can be computationally demanding and require specialised skills and resources. Additional challenges are related to how mapping abstractions do not always capture all the complexities of landscape dynamics, recognising that not all characteristics noted by experts could be tangibly incorporated into the mapping. A limited body of research has investigated the incorporation of both tangible and intangible characteristics of space. This challenge, along with others on the representation of different aspects of space on a single map, has been noted in many studies, such as Röing et al. (2021). Additionally, although local experts are familiar with these landscapes, surrounding communities' lived experiences and characterisations are equally significant. Thus, there is a need for interdisciplinary collaboration among various stakeholders and ongoing revisions of these maps to gain a better understanding of the complexities inherent in this landscape.

7.4. SUMMARY OF THE CHAPTER

This chapter has discussed the findings from *Chapter 6: Analysis and development of a framework for post-mining and urban landscape characteristics – A Case Study of Gauteng*. The findings are discussed in three parts. First, the discussion of the findings of the post-mining and urban landscape characteristics identified from the literature and local experts notes that the characteristics of the two landscapes are mostly different and opposing when based on literature. Another interesting finding was that local experts reported that most of their conceptualisations of both landscapes were influenced by literature. However, the characteristics of the two landscapes, as identified from local experts, demonstrate that the characterisation of these two landscapes bears some similarities. This finding, therefore, suggests that the differences in the two landscapes, as indicated by the landscapes' general characterisations identified in the literature, are insufficient and underscores the importance of contextual conceptualisations of landscapes and their characteristics.

Second, the discussion of the mapping results notes that the mapping was different depending on whether they were mapped based on being informed by literature or local expert characterisations. The conventional literature-based characterisations tend to depict distinct landscapes, whereas regional and expert-driven approaches reveal overlap and coexistence. The discussion noted that the maps informed by the characteristics derived from local experts had a larger spatial footprint than those informed by literature-derived characteristics. The discussion also pointed out that the general outlines of the mapped results were similar to existing maps of Gauteng's mining and urban land uses. Another finding emerging from the discussion on mapping and the validation of the mapping results, which presents and quantifies the differences between the maps informed by the literature and local expert inputs, was the effect of different mapping techniques on the spatial outcomes of each map. The discussion acknowledges that the fuzzy and weighted overlay mapping techniques presented landscapes comprising multiple characteristics more effectively. However, it also highlights that fuzzy overlay was the most preferable technique in the Gauteng context, where the boundary between the post-mining and urban landscape was unclear.

Third, the potential applications of the framework were discussed, emphasizing how the integration of post-mining and urban landscape characteristics can be used to explore the spatial, temporal, and multifunctional dimensions of the Gauteng landscape. This was illustrated through spatial overlap, temporal coexistence, and sequencing between post-mining and urban landscapes. By presenting an integrated perspective, the framework discussion encourages re-evaluating traditional notions of separate landscapes. It offers insights into post-mining and urban landscapes' interconnected and integrated nature. Therefore, the framework discussion sheds light on the complexity and fluidity of post-mining and urban landscapes, emphasizing their integrated nature and relevance in guiding decision-making and planning, especially in rapidly changing regions like Gauteng. However, the chapter also discusses the limitations of the proposed framework, which pertain to data, reference data, computational demands, mapping abstractions, and the need for interdisciplinary collaboration to account for both tangible and intangible characteristics and community perspectives.

CHAPTER EIGHT: CONCLUSIONS AND RECOMMENDATIONS

8.1. INTRODUCTION

This chapter concludes this research by summarising the research findings and how the research propositions are addressed in this study. First, the research objectives are reviewed to present how they have been achieved throughout the study. Second, a summary of the contributions to knowledge in the interdisciplinary field is given. Thirdly, a discussion of the research limitations and recommendations for further investigation are presented.

8.2. REVIEW OF RESEARCH OBJECTIVES

As stated in Chapter 1, this study aims to develop a GIS-based framework for conceptualising, integrating, analysing, visualising and managing the historical and contemporary characteristics of Gauteng's urban and post-mining landscapes. To achieve this aim, three specific objectives were addressed: 1) to critically analyse historical and current documentation, legislation and mapping of mining-related activities in Gauteng to ascertain their role in the conceptualisation of the province as an urban and post-mining landscape, 2) to design a GIS-based framework for evaluating the merits of integrating historical and contemporary data to conceptualise the Gauteng landscape as a multi-faceted urban and post-mining landscape, 3) to test the usefulness of the proposed framework in informing the representation and conceptualisation of post-mining and urban landscapes and its potential applications as a tool for decision-making on the management of mining and post-mining landscapes in urban development using different mapping techniques.

To achieve objectives 1 and 2, this research reviewed literature, spatial data and document and survey data. Objective 1 is discussed in *7.2. Key characteristics of post-mining and urban landscapes.* Two research gaps were identified through the literature review and questionnaire data collection. The first gap relates to the lack of a framework for integrating post-mining and urban landscapes where these two landscapes co-exist. The second relates to the limitations of existing representations and conceptualisations of the post-mining and urban landscapes in some contexts, particularly where these two landscapes co-exist. This research, therefore, was designed to fill these gaps. The literature review was conducted to fill gaps 1 and 2 partially.

Additionally, a questionnaire was sent to local experts for more contextual information on the characterisation of these two landscapes. The questionnaires to local experts were innovative for their contextual insights into the characteristics of the Gauteng landscape. The observation of the above-mentioned key characteristics identified from the literature, the survey analysis results and key characteristics associated with post-mining and urban landscapes identified by local experts were used to propose a preliminary framework for integrating post-mining and urban landscapes in Gauteng in

Chapter 6. Additionally, Chapter 2 provided an overview of the study area, also contributing insights to the conceptualisation of the post-mining and urban landscapes within this region. By doing so, gap one was further filled.

Chapter 3 reviewed assemblage theory and its applications in understanding space, the existing conceptualisations of landscapes, post-mining landscapes and urban landscapes. Chapter 4 reviewed the applications of GIS for the representation of real-world abstractions and techniques for integrating different spatial criteria, such as landscape characteristics, including MCDA, AHP, Fuzzy overlay, Weighted overlay and Random forest classification, to fulfil this research.

To achieve objective 2, a GIS-based framework was conceptualised and proposed in Chapter 6. The framework was conceptualised after considering findings from Chapter 6, *6.2. Identification of landscape characteristics*. Chapter 5 outlined the methods of criterion identification, weighting determination, standard rating formulation, and the data collection strategy involved. The structure and the components of the framework are presented in Chapter 6, *6.3. Conceptual framework of a GIS-based framework for the integrated mapping and spatial analyses of post-mining and urban landscape characteristics in Gauteng*, while the conceptual framework is further elaborated in Chapter 7 (Figure 20). The post-mining and urban landscape characteristics were mapped based on the proposed framework, which presented the combination of characteristics identified from the literature with some from local experts to demonstrate the potential outcomes of integrating the landscape characteristics. These maps provide a quantitative and objective reference for landscape character integration. The landscape characteristics are innovative for contextual characterisations from local experts, of post-mining and urban landscape characteristics. Additionally, characteristics were used to map the urban and post-mining landscape characteristics during the framework development process to fill the gap.

The last objective, objective 3, was aimed at assessing the usefulness of this framework; the mapping was validated using four performance-evaluating exercises in Chapter 6. Moreover, the usefulness of such a study integrating the seemingly distinct post-mining and urban landscapes was further explained, drawing from the consultation of literature on the applications of such landscape character studies for decision and policy-making. GIS framework applications in mining and urban landscape studies were discussed in Chapter 4, *4.5. GIS-based framework applications in urban and mining-related research*. Chapter 4 also included a section on critical mapping, *4.3.1. Critical cartography* states the importance of questioning the representation of space and investigating alternatives.

Regarding the validation evaluation of the proposed framework and the integration of landscape characteristics, four validation techniques were applied, including confusion error matrices, cross-evaluation of values, an assessment of the areal coverage of each landscape and a change detection assessment of the maps generated using the three mapping techniques applied in the mapping of post-mining and urban characteristics in this study. This exercise assessed how well each mapping technique integrated the post-mining and urban landscape characteristics per the proposed framework. The results of these exercises were reflected in several sets of comparative tables, and the quantitative analyses of the data collected from all exercises undertaken within this study were reflected together to answer the research question introduced at the start of the research study.

8.3. RESEARCH CONCLUSIONS

Considering the integration of the post-mining and urban landscape characteristics for a holistic understanding of the province's landscape, the research question concerning the applications and limitations of the proposed framework has been answered. The framework proposed in this research can support the integration of post-mining and urban landscape characteristics for an integrated conceptualisation and analysis of these landscapes and potentially serve as a tool for informing knowledge and managing the Gauteng landscape and similar contexts with contrasting landscapes. According to the research process and particular methods outlined in Chapters 1 and 6, the conclusions of this research are drawn from the literature and content analysis, survey material, and experimentation in the form of the three mapping techniques applied and the validation of the mapped results.

8.3.1. Conclusions from the literature analysis

To understand the conceptualisation of post-mining and urban landscapes in Gauteng, literature (both international and local), historical maps and other archival materials were reviewed to inform the research design to solve these problems. The main characteristics of these landscapes are identified: On the one hand, post-mining landscapes are characterised mainly by characteristics related to 1) artificial, 2) inaccessibility, 3) assemblage, 4) social impact, 5) abandoned mines and infrastructure, 6) economic decline, 7) natural resource use and degradation, 8) population changes, 9) rehabilitation; and 10) transformation. On the other hand, urban landscapes are characterised by characteristics related to 1) artificial, 2) density, 3) economic development and opportunities, 4) mobility and mutual accessibility, 5) natural resource use and degradation, 6) social impact and conflict, 7) transformation, and 8) assemblage. These findings demonstrated a difference in how post-mining and urban landscapes are characterised and described. As discussed in chapters 6 and 7, these findings differed slightly from those obtained from local experts, as presented below.

8.3.2. Conclusions from the questionnaires and interviews with local experts

Questionnaires were administered online through a Google Forms survey and survey-style interviews. The surveys and interviews were conducted to understand how these two landscapes are characterised and where their respective characterisations and conceptualisations are derived. Details are described in Chapter 6, *6.2. Identification of landscape characteristics.*

The findings from the questionnaires and survey are summarised as follows:

The characterisations of the two landscapes differed slightly from those identified in *6.2.1. Content analysis: Literature, legislation and other archival material*. Post-mining and urban landscape characteristics were similar across questionnaire participants. Most participants reported that they stem from literature when asked where their definitions and characterisations of these landscapes came from. This finding indicates that literature, archival material, and mapping are significant in conceptualising the Gauteng landscape as characterised by distinct post-mining and urban landscapes.

While these experts agreed that literature and other archival material mainly influenced their conceptualisations of these landscapes and their characteristics, it is also suggested that these two landscapes are not that distinct. The local experts indicated that the current conceptualisations and characterisations of these landscapes are not adequate for contextual characterisations of these landscapes. The participants identified data missing from the definitions, conceptualisations and mapping of Gauteng's urban, mining and post-mining landscapes. Identifying new characteristics highlights the uniqueness of Gauteng's urban and post-mining landscapes and the Gauteng landscape. As such, this exercise identified the need for more contextual characterisations of Gauteng's urban and post-mining landscape.

8.3.3. Conclusions from the case study

The proposed framework was developed using this case study. Due to data availability and time constraints, data on community characterisations and perceptions of their surrounding post-mining and urban landscapes were not included in this study as initially anticipated. These data were excluded to include tangible landscape characteristics that could easily be modelled in a GIS. The associated data involved in the mapping were collected and processed in the database. The detailed processes of identifying contextual landscape characteristics were illustrated in the case study, and the framework was developed to reflect these specific characterisations to show the viability of the framework proposed in the research. Gauteng is a good case study for the research undertaken because of its co-existence of mining, post-mining, and urban landscapes and activities. This case study provides insight into the integration of overlapping landscapes and how contrasting landscapes could be thought of in similar mineralised urbanisation contexts. Moreover, the findings demonstrate the importance of contextual mapping for understanding the landscape.

8.3.4. Conclusions from the mapping of landscape characteristics

The mapping validation showed spatial variations in mapping the two landscapes in several ways. First, variations in the spatial extent of both landscapes were visible depending on whether literature or local expert-identified characteristics were being mapped. Second, there were variations in how the landscapes were spatially represented depending on the mapping technique applied. Two mapping techniques, fuzzy overlay and weighted overlay, present the post-mining and urban landscape characteristic values ranging from 0 to 1, where areas with no or little post-mining or urban landscape characteristics have values closer to 0. However, random forest classification does not use a graduated scale range. It presents areas with no post-mining or urban landscape characteristics with a value of 0 and those with these characteristics with a value of 1. The maps derived using local expert knowledge covered larger areas across all three maps than the mapping characteristics identified from the literature. The maps derived using random forest classification depicted the least areal coverage of post-mining and urban landscape characteristics, owing to their use of a binary rather than graduated range scale.

The differences and changes observed in these maps show that despite the maps' similarities based on characteristics identified from literature with current and existing mapping of both these landscapes, these maps do not represent all the characteristics associated with these landscapes. These maps, therefore, stand the risk of miscommunicating what exists on the ground with what is on the map. Thus, integrating post-mining and urban characteristics for the mapping of Gauteng could potentially serve as a tool to inform a more holistic picture and understanding of the landscape. This would be useful for numerous reasons, such as the complete representation of the Gauteng landscape. The two maps that best present the co-existence of post-mining and urban landscape characteristics are fuzzy and weighted overlay. However, in a situation where the aim is to integrate characteristics, the fuzzy overlay is most suitable as it maps characteristics in a way that shows the membership of each characteristic per grid cell and can demonstrate the blurred boundaries between landscape characteristics.

8.4. CONTRIBUTIONS OF THE RESEARCH

This research contributes to the conceptualisation of post-mining and urban landscapes in Gauteng, characteristic landscape mapping and GIS. Gauteng is characterised by rapid urbanisation and mining activity, and the relationship between these two landscapes is often a key topic in urban planning. The data preparation in the database for the model included in the framework belongs to the field of GIS and was analysed using GIS technology. This research has explored an approach to using GIS for integrating post-mining and urban landscape characteristics.

The primary research outcomes reflecting the contributions of this research to the body of knowledge include 1) new knowledge on key characteristics of post-mining and urban landscapes in Gauteng and their origins, 2) an approach to integrate different landscape characteristics using assemblage thinking, 3) a proposal for a framework for spatially integrating the post-mining and urban landscape characteristics in Gauteng (and other similar contexts) to assist in the integrated conceptualisation and visualisation of the landscape, and 4) challenging the current visual and spatial representation of post-mining and urban landscapes in Gauteng. This study indicates that the proposed GIS-based framework can address the challenges of integrating seemingly distinct and complex landscape characteristics. In sum, five main points of contributions dedicated to this research are highlighted as follows:

First, this research has demonstrated the differences between literature-based and contextual characteristics of post-mining and urban landscapes and the associated data/information sources. The characteristics identified at the contextual level could be used to bridge the gap of a lack of contextual information and assist with a more contextual conceptualisation of post-mining and urban landscapes for a holistic and contextual understanding of the Gauteng landscape.

Secondly, this research proposes a framework that can be regarded as a prototype for integrating post-mining and urban characteristics for land use planning. This proposed framework was designed based on local expert input gathered through a survey during the framework development process. It was developed by using an accessible MCDA process and GIS to keep its complexity low (i.e. relatively simple rationale). This proposed framework can be used as a guideline to start thinking through the relationship between mining and urbanisation in Gauteng, its implications for managing both these landscapes, and to support planning practitioners in making land-use decisions in site planning, particularly in thinking through future developmental trajectories.

Third, the mapping techniques applied within this research do not represent these landscapes as points or polygons traditionally used to map these landscapes. These methods of representing these landscapes, particularly post-mining ones, are often restrictive and do not consider that mining can have far-reaching impacts on its surroundings and the subsurface.

Fourth, this research has developed a qualitative and quantitative approach for integrating post-mining and urban landscape characteristics and a standard means of providing usable data for the model (i.e. the steps of data pre-processing and criteria elimination). This approach could provide planners with a more holistic way to support decision-making and development planning.

Fifth, this study has demonstrated the importance of contextual landscape characterisations, GIS visualisation and spatial analysis in understanding a landscape, especially those with conflicting landscapes.

Thus, to answer the main research question, the proposed framework can contribute to the theoretical definition of landscapes as assemblages while providing a basic framework for balancing the competing demands and integrating policies for multiple land uses within a given area. This helps contribute to an integrated understanding of an area such as Gauteng. The proposed framework demonstrates several applications:

One of the first demonstrated applications of this proposed framework has been to give insight into the importance of contextual information, knowledge mapping and understanding spaces. This is seen with the differences in the characterisation of post-mining and urban landscapes between those identified from the literature and local experts.

The other demonstrated application of the proposed framework has been challenging the current representation of post-mining and urban landscapes and the presentation of an alternative to the representation and visualisation of post-mining or mining and urban landscapes in Gauteng by depicting them as integrated rather than separate. By providing an alternative representation of these landscapes as integrated, this research potentially provides insights into new conceptualisations of urban landscapes, post-mining landscapes and mineralised urbanisations.

Another demonstrated application of the proposed framework has been showing the many ways post-mining and urban landscapes interact in space. They are connected while further confirming the blurred boundaries between the two landscapes.

The above-demonstrated integration of these two landscapes suggests that while the Gauteng province no longer relies on mining for economic development, mining activities still play a prominent role in this province's economy and spatial development. This consideration is important in a rapidly urbanising context, such as Gauteng, which is characterised by a high demand for natural resources such as. Such a framework and integrated view of the Gauteng landscape starts to provide some insight into future development trajectories in the province.

The value of the applications mentioned above are many in the context of informing decision-making, particularly related to the management of mining landscapes. The integrated framework could provide a structured and holistic approach to rehabilitation efforts considering environmental, social and economic factors and surrounding urban processes. By so doing, the framework could also aid in modelling and planning rehabilitation and the reintegration of remediated land. Moreover, the proposed framework enhances a better understanding of post-mining and urban landscapes and their intersection in Gauteng, which has the potential to inform policy-making within this space. By providing an alternative representation of these landscapes as integrated, this research potentially provides insights into new conceptualisations of urban landscapes, post-mining landscapes and mineralised urbanisations and their management. Moreover, the integration of the characteristics of these two landscapes is useful for providing insights into the complex spatial relationship between post-mining or mining and urban landscapes in Gauteng.

8.5. LIMITATIONS OF THE RESEARCH

Five key aspects of the limitations of the research are acknowledged as follows. Firstly, any framework is as good as the data involved, as the data used in the development of any framework, in particular, the quality of the data, strongly influences the resultant framework and results. Secondly, the framework was developed in a loosely coupled form rather than a software package, which integrates all components automatically. The main reason for this limitation is due to time and technical limits. Thirdly, the framework, while considering some historical data, the data is relatively recent and only dates back to 1990. However, data of a mine reef in 1927 is used to demonstrate the spatial overlap. This limitation is because some of the historical data is not readily available in a spatial format, also using a goldfields reference system that is no longer in use. Fourthly, the research primarily uses secondary data. Secondary data may have some limitations, such as coarse resolution and lack of data documentation. This is because secondary data was available in a format that could not be readily used in a GIS and, therefore, had to be converted into a usable format.

The study does not include primary data from surrounding communities, which would provide a level of nuance in how the landscape is characterised. The study was conducted during the COVID-19 pandemic with government-imposed lockdown restrictions. The nature in which the data would have been collected in hardcopy maps would have been high risk. Another reason is that of time. It was considered that data/information for some criteria, such as community perceptions, must be converted to quantitative (scaled) data for use in the mapping and integration. This conversion would have required more time.

Moreover, another consideration was that some characterisations of these landscapes might be intangible, challenging their integration. However, this research seeks to further expand on the proposed framework and incorporate insights from surrounding communities in the future for more local insights. Finally, developing the databases was found to be time-consuming as much data was collected and processed during this process. Nevertheless, the process could be shortened if the relevant data were accessible in the required formats.

8.6. RECOMMENDATIONS FOR FUTURE RESEARCH

This research proposes future research as follows: First, including information from local communities so that characterisations of post-mining and urban landscapes are more encompassing. Second, continuous workshops with individuals in related fields and stakeholders could be done to fully demonstrate the potential of such a framework that integrates post-mining and urban landscape characteristics and finalise it. Further work includes special studies on specific criteria and qualitative criterion quantification, such as public perceptions data. Third, an automatic tool could be developed based on the framework (an improved prototype) to improve the understanding and conceptualisation of the Gauteng landscape. The tool could be available and incorporated into mapping software such as ArcGIS. In addition, a module/sub-system, especially assessing the communication with existing mining and urban development-related policies and legislation, could be incorporated into the integrated framework.

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APPENDICES

Appendix 1: Questions incorporated into the Google Form online survey

Project Title: A GIS framework for the integrated conceptualisation, analysis and visualisation of Gauteng's complex historic and contemporary post-mining urban landscape.

Purpose of the study:

The purpose of the study is to develop a GIS-based framework for the integrated conceptualisation, analysis, visualisation and management of urban and post-mining characteristics of the Gauteng landscape.

Purpose of the interviews:

Question set 1 (Directed at industry professionals and experts): To identify key concepts and data that should be incorporated into the framework. The aim would be to identify data and concepts that are not currently captured in other conceptual and spatial frameworks used for research, planning and policy-making.

Question set 2 (Directed at surrounding communities): To gather information on perceptions of the landscape that are not currently incorporated in urban and post/mining mapping.

Procedure for participation:

Telephonic interviews will be conducted with local experts. Local experts will be contacted via email prior to the commencement of the interviews. Upon acceptance of the interview, industry experts will be sent consent forms to fill in. Consent and interest in participating in the study will further be verified on the day of the interview where the participant will be asked for verbal consent.

The participatory mapping will be conducted in two ways. It is proposed that the community mapping exercise be conducted using a laminated printout of a map and markers (new for each participant). Gloves, masks and sanitiser will be made available for both the researcher and the participant. Photos of the maps will be taken so that analysis can carry on and the original maps will be sealed for a month. In this case, verbal consent will be required from participants. Alternatively, it is proposed that the participatory mapping is conducted using web-based platforms such as Google Maps or Google Earth. In this case, community leaders will be approached telephonically to let them know about the study and also for guidance on participants. An online consent form will be made available at the start of the interview. Where applicable, mobile data costs will be covered by the researcher.

The interview as a whole should not take longer than 60 minutes to complete.

Potential benefits:

Respondents and/or survey participants will receive no direct benefits from participation. I hope that in the future other people might benefit from this study through an improved integrated understanding of the Gauteng landscape.

Confidentiality:

Any potential loss of confidentiality will be minimised by storing data on a password-protected computer in a locked office. All participants will be assigned pseudonyms, which will be linked to one password-protected document.

Question set 1: Experts in conceptualisation and mapping of mining, post-mining and urban landscapes

1. What are the characteristics of mining and post-mining landscapes and their cartographic representations?
2. What characterises urban land use and/or development in Gauteng and its cartographic representations?
3. Where do these definitions or characteristics come from? I.e. do they come from a set of legislation, historical documents, historic maps or regulatory frameworks?
4. In your opinion, are the current definitions of mining, post-mining and urban landscapes and their cartographic representations sufficient? Why do you say this?
5. How do the definitions of mining, post-mining activities and urban landscapes influence the understanding and management of mining and urban landscapes in Gauteng?
6. What implications do post-mining landscapes have on past, present and future development in the province? And vice versa.

Appendix 2: Ethics Certificate

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Research Office

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

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H20/06/15**
PROJECT TITLE	A GIS framework for the integrated conceptualisation, analysis and visualisation of Gauteng's complex historic and contemporary post-mining urban landscape
INVESTIGATOR(S)	Miss S Khanyile
SCHOOL/DEPARTMENT	Geography, Archaeology and Environmental Studies/
DATE CONSIDERED	19 June 2020
DECISION OF THE COMMITTEE	Approved Risk Level: Low
EXPIRY DATE	04 October 2023

DATE 05 October 2020 **CHAIRPERSON** J Knight
(Professor J Knight)

cc: Supervisor : Professor S Merlo

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. 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 to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

____
Signature

Date ______/______/______

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

Appendix 3: Spatial data gathered as identified from the literature review

Data layer	Category	Associated concept	Format	Scale/ resolution	Source
Witwatersrand Goldfields (1886)	Historical proclaimed gold mining areas	Historical, land use, assemblage, temporal, spatial	Scanned document	Gauteng	UCT online archives, Sibanye Gold
Mining lease area	Mining concessions	Governance, economic development and opportunities	Vector shapefiles	Gauteng	Department of Mineral Resources
Active mines	Mines (shaft, location, ownership, minerals)	Natural resource exploitation, economic development and opportunities	Vector shapefiles	Gauteng	Department of Mineral Resources
Derelict and ownerless mines	Mines (shaft, location, ownership, minerals)	Natural resource degradation, sustainable urban development challenge, economic decline and collapse	Vector shapefiles	Gauteng	Department of Mineral Resources / Council for Geosciences
Mines	Mines (shaft, location, ownership, minerals)	Economic development and opportunities, natural resource exploitation	Vector shapefiles	Southern Gauteng	Department of Mineral Resources / Council for Geosciences
Mine residue areas	Mine tailings	Natural resource degradation, sustainable urban development challenge	Vector shapefiles	Gauteng	Gauteng Department of Agriculture and Rural Development
Land use (1956)	Historical, land use	Land cover/use, assemblage, artificial, malleable	Scanned document	Gauteng	Fair et al. 1957
Land use (1976)	Historical, land use	Land cover/use, assemblage, artificial, malleable		Gauteng	Fair et al. 1979
Land use change (1990, 2000, 2013)	Land use	Land cover/use, assemblage, artificial, malleable	Vector shapefiles	Gauteng, 30m	GeoTerra Image
Minerals Act (Act 50 of 1991)		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Minerals and Energy
Fanie Botha Accord (1970)		Governance, natural resource degradation, natural resource exploitation, sustainable urban	Document	South Africa	Department of Mineral Resources

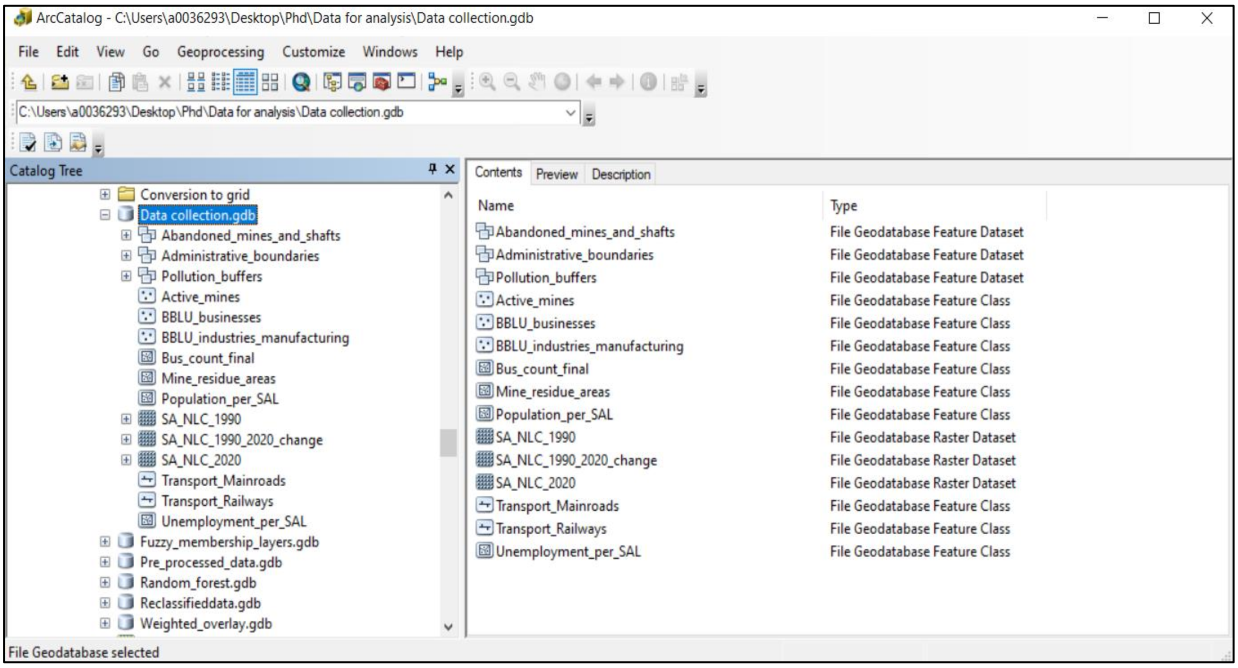
		development challenge			
Mining Rights Act (Act 20 of 1967	Legislation and policies	Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Mineral Resources
Mines and Mineral Development and Regulation Act (Act 7 of 1957)		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Mineral Resources
Mines and Works Act (Act 27 of 1956)		Governance, economic development and opportunities	Document	South Africa	Department of Mineral Resources
General Mining Act 1854		Governance, economic development and opportunities	Document	South Africa	Department of Mineral Resources
Minerals, Petroleum and Resources Development Act (Act 28 of 2002)		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Mineral Resources
Nuclear Energy Act (Act 29 of 1996)		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Minerals and Energy
National Environmental Management Act (Act 107 of 1998)		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Environmental Affairs
National Water Act (Act 36 of 1996)		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Water and Sanitation

Water Amendment Act (Act 58 of 1997)		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Mineral Resources
Mine Health and Safety Act (Act 29 of 1996)		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Mineral Resources
Constitution of the Republic of South Africa 1996		Governance, culture and heritage	Document	South Africa	Republic of South Africa
National Mine Closure Strategy		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge, economic decline and collapse, economic development and opportunities	Document	South Africa	Department of Mineral Resources
White Paper on Spatial Planning and Land Use Management Act 2013		Governance, natural resource exploitation, sustainable urban development challenge, economic development and opportunities, malleable, spatial	Document	South Africa	Republic of South Africa
National Environmental Management: Waste Act 2008		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Environmenta l Affairs
National Environmental Management: Air Quality Act 2004		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Environmenta l Affairs

Minerals Petroleum and Resources Development (Amendment Act) 2004		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Mineral Resources
Atmospheric Pollution Prevention Act (Act 45 of 1965)		Governance, natural resource degradation, natural resource exploitation, sustainable urban development challenge	Document	South Africa	Department of Mineral Resources
Gauteng Spatial Development Framework 2030		Governance, natural resource exploitation, sustainable urban development challenge, economic development and opportunities, malleable, spatial	Document	Gauteng	Gauteng Provincial Government
Gauteng Pollution Buffer Zones Guideline 2017		Governance, natural resource degradation	Document	Gauteng	Gauteng Department of Agriculture and Rural Development
Gauteng Environmental Framework 2018	Environmental framework zones	Governance, natural resource exploitation, sustainable urban development challenge, economic development and opportunities, malleable, spatial, malleable	Vector shapefiles	Gauteng	
Quality of Life Survey IV 2018/19	Socio-economic data, quality of life data	Social justice, demographic data	Vector shapefiles	Gauteng	Gauteng City-Region Observatory
Gauteng transport network	Roads, railway, BRT and taxi routes	Mobility and mutual accessibility	Vector shapefiles	Gauteng	Gauteng Economic Development
AfriGIS Bizcount	Business locations	Economic development and opportunities	Vector shapefiles	Gauteng	AfriGIS
Census 2011	Demographic data	Density, Social justice, demographic data	Vector shapefiles	Gauteng	Statistics South Africa
Holden's map of Johannesburg (1929)	Historical proclaimed gold mining areas	Historical, land use, assemblage, temporal, spatial	Raster	Gauteng	UCT online archives, Sibanye Gold

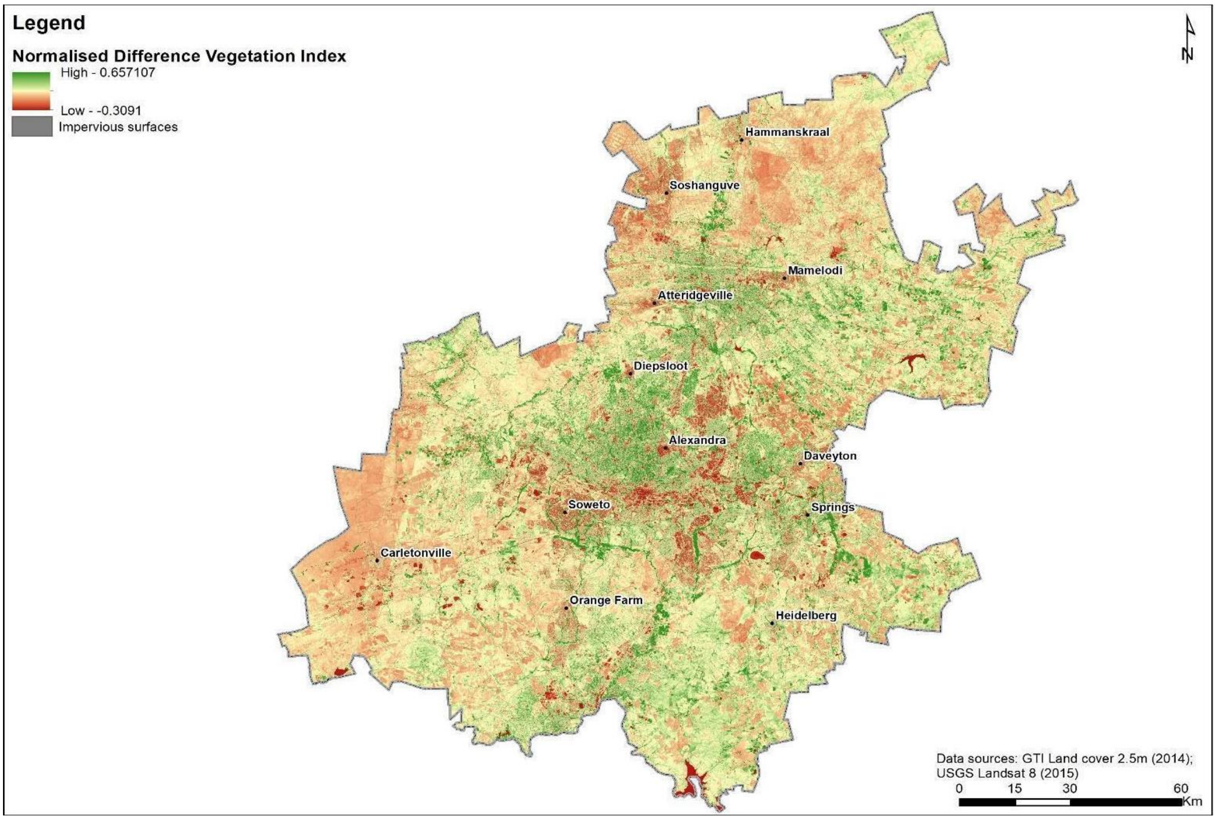
Gold mines and minerals of the greater Witwatersrand and Orange Free State (1949)	Historical proclaimed gold mining areas	Historical, land use, assemblage, temporal, spatial	Raster	Gauteng	UCT online archives, Sibanye Gold
Map of Pretoria and Heidelberg goldfields (1887)	Historical proclaimed gold mining areas	Historical, land use, assemblage, temporal, spatial	Raster	Gauteng	UCT online archives, Sibanye Gold
Witwatersrand (1890) Mendelssohn	Historical proclaimed gold mining areas	Historical, land use, assemblage, temporal, spatial	Raster	Gauteng	UCT online archives, Sibanye Gold
Jeppe Southern Goldfields (1896)	Historical proclaimed gold mining areas	Historical, land use, assemblage, temporal, spatial	Raster	Gauteng	UCT online archives, Sibanye Gold
Wyld's new map of Witwatersrand Goldfields and district (1889)	Historical proclaimed gold mining areas	Historical, land use, assemblage, temporal, spatial	Raster	Gauteng	UCT online archives, Sibanye Gold
Topographic data	Relief, land use/cover	Artificial, malleable, spatial, mutual accessibility and mobility	Vector shapefiles	Gauteng	Chief Directorate: National Geospatial Information

Appendix 4: Geodatabase of collected data

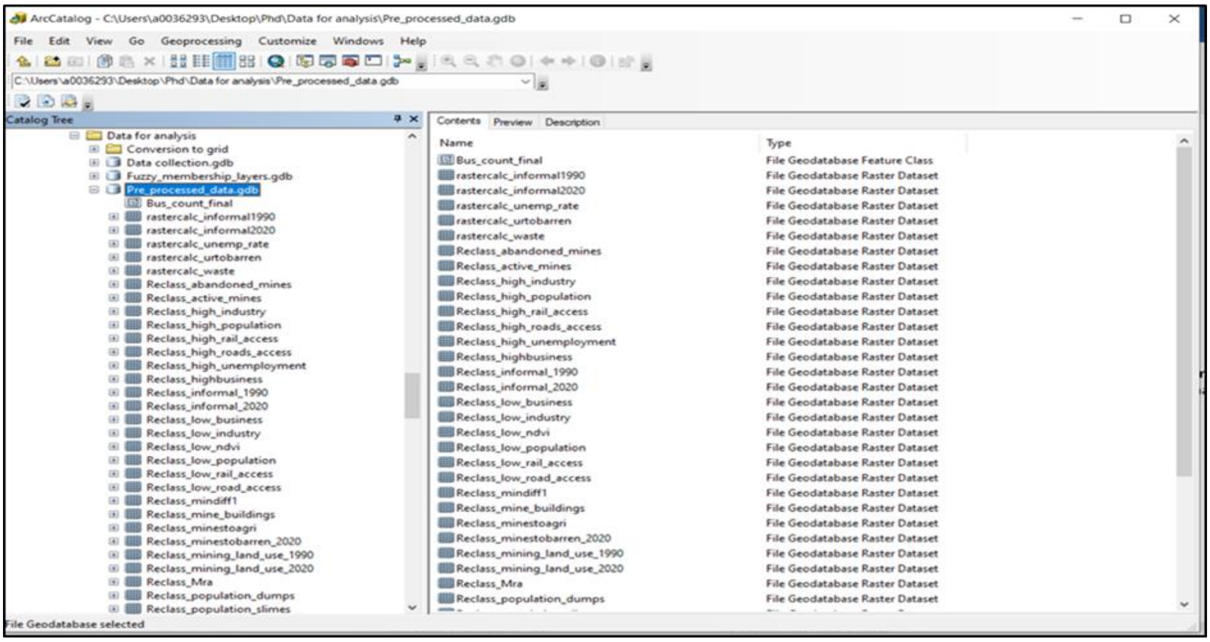


Appendix 5: NDVI of Gauteng

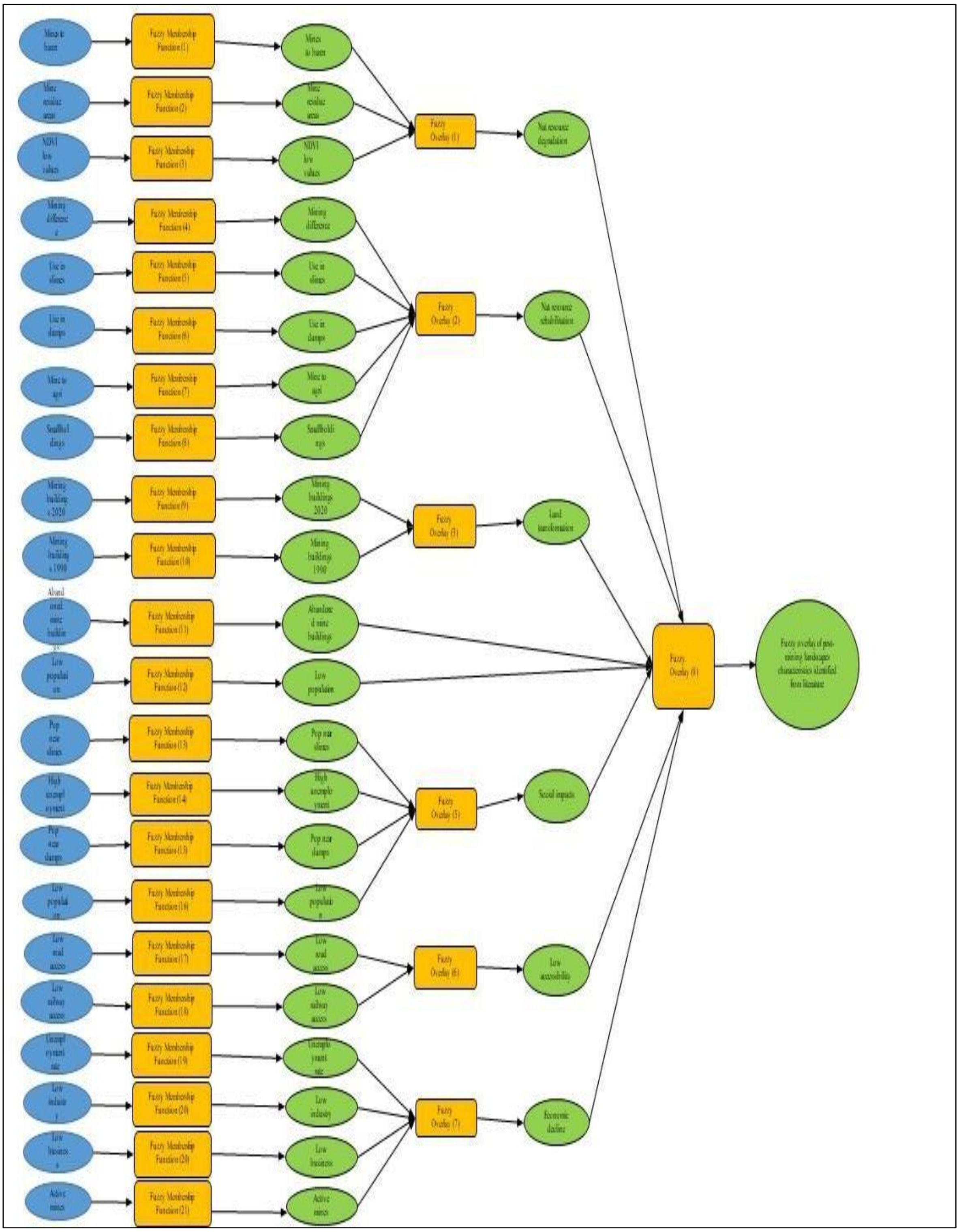
NDVI is derived from satellite imagery, which captures reflected light. Lush and broad-leaf vegetation absorbs visible light from the sun and reflects near-infrared light. Unhealthy or sparse vegetation absorbs limited sunlight and reflects more visible and less near-infrared light. The NDVI is calculated by subtracting the red band from the near-infrared band.



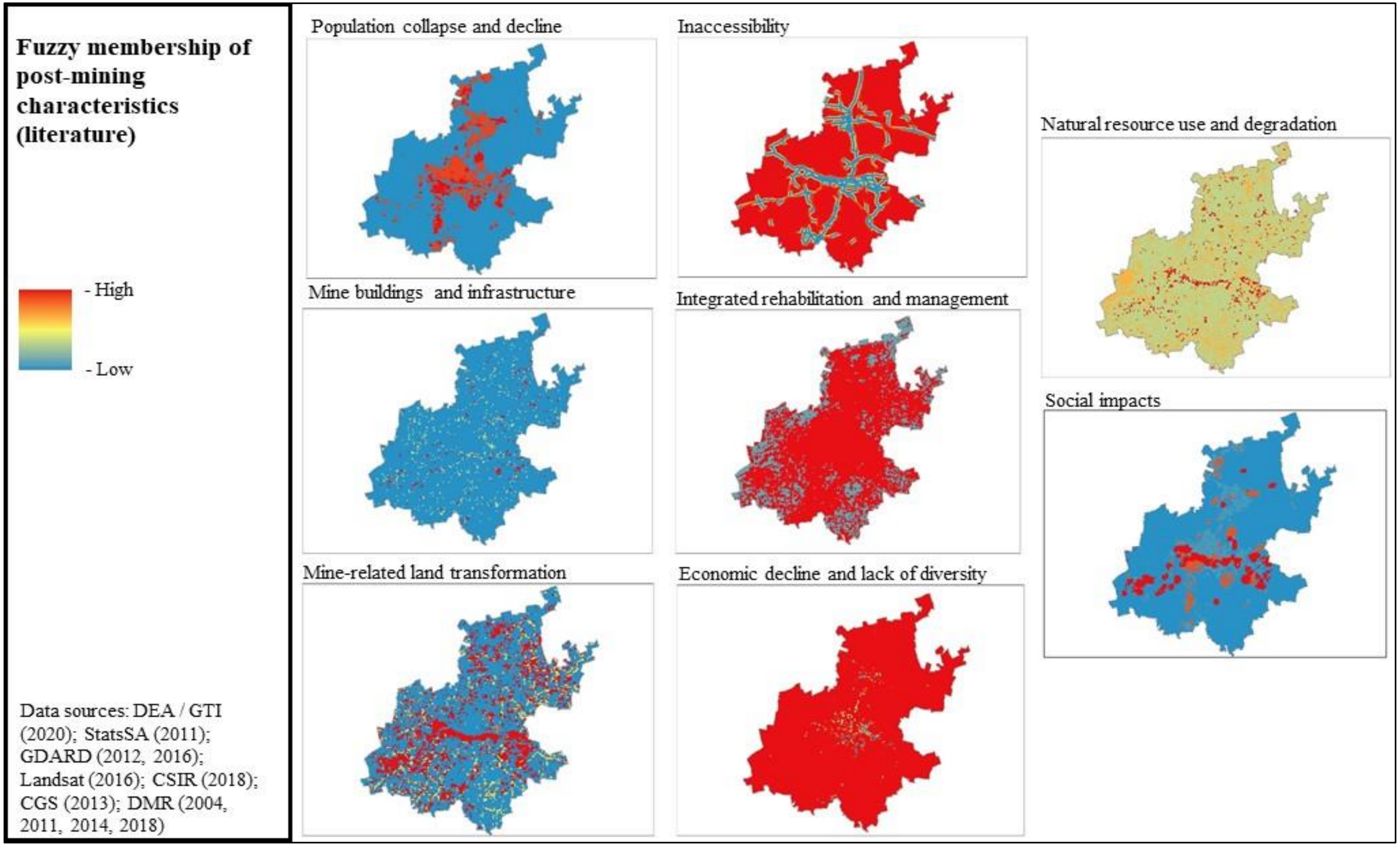
Appendix 6: Geodatabase of pre-processed data



Appendix 7: Fuzzy overlay Arcmap model of post-mining landscape characteristics from literature



Appendix 8: Enlarged fuzzy membership map of the post-mining landscape characteristics from literature



Appendix 9: Fuzzy membership of the post-mining landscapes characteristics from local experts

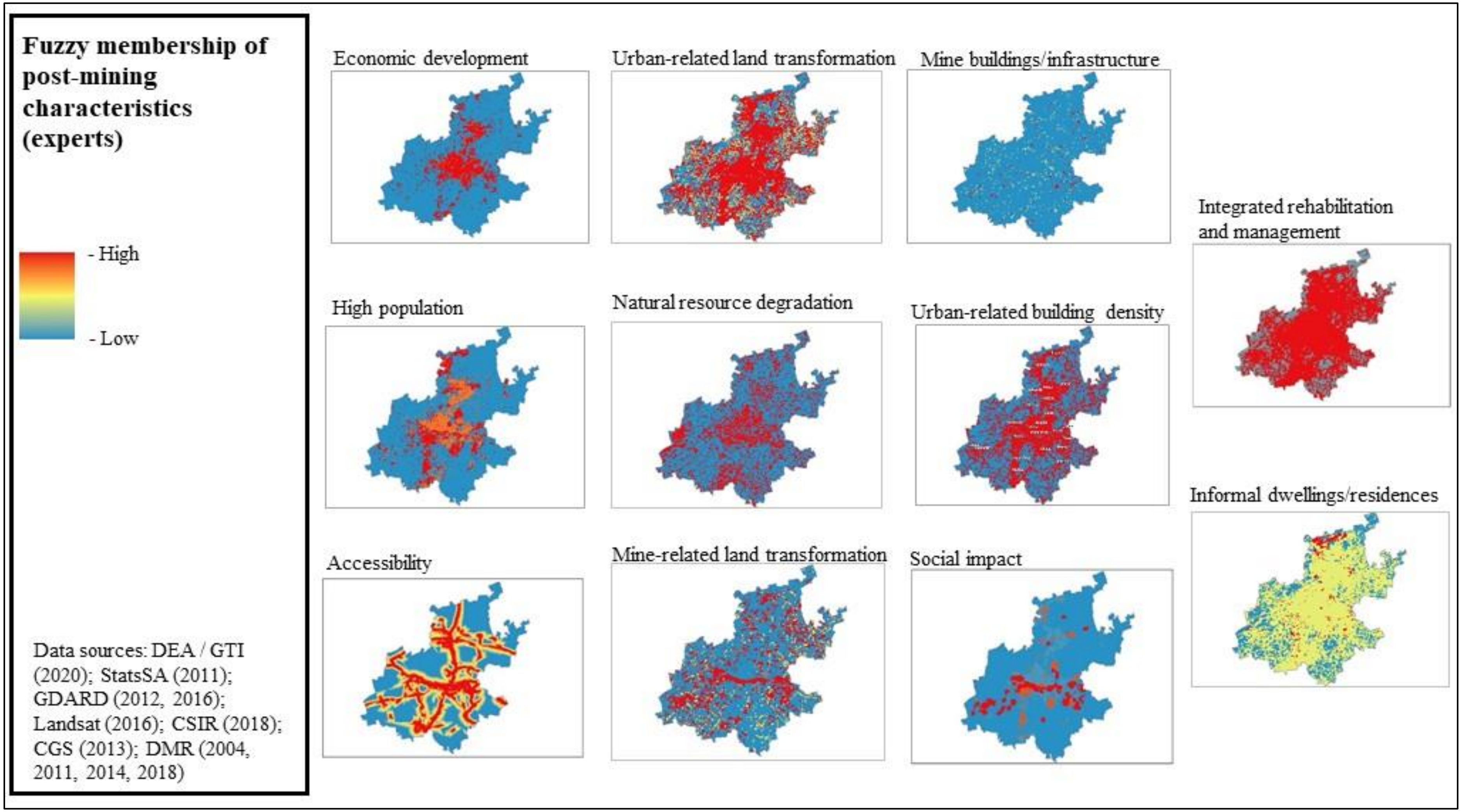
CHARACTERISTIC	MEMBERSHIP	FUNCTION
Economic development and diversity:		
Business count per km^2	Favours high values	Linear
Industry count per km^2	Favours high values	Linear
Active mines count per km^2	Favours high values	Linear
Abandoned mines per km^2	Favours high values	Linear
High population density:		
High population count per km^2	Favours high values	Linear
Integrative rehabilitation and management:		
Post-mining land uses per km^2	Favours high values	Linear
Development within mine dumps buffer per km^2	Favours high values	Linear
Development within slimes buffer per km^2	Favours high values	Linear
Smallholdings per km^2	Favours high values	Linear
Mines to agriculture per km^2	Favours high values	Linear
Social impact:		
Proportion of population within proximity of mine dumps per km^2	Favour high values	Linear
Proportion of population within proximity of slimes per km^2	Favour high values	Linear
High unemployment per km^2	Favour high values	Linear
High population count per km^2	Favour high values	Linear
Accessibility:		
Road accessibility (within 500m) per km^2	Favour high values	Linear
Railway accessibility (within 1000m) per km^2	Favour high values	Linear
Abandoned mines and infrastructure:		
Abandoned mines per km^2	Favour high values	Linear
Mining-related buildings per km^2 (1990)	Favour high values	Linear
Mining-related buildings per km^2 (2020)	Favour high values	Linear
Mining-related land transformation:		
Historical mining-related land cover/use (1990) per km^2	Favour high values	Linear
Present-day mining-related land cover/use (2020) per km^2	Favour high values	Linear
Natural resource use and degradation:		
Low NDVI values per km^2	Favour high values	Linear
Mine residue areas per km^2	Favour high values	Linear
Mines to barren/eroded per km^2	Favour high values	Linear
Urban to barren/eroded per km^2	Favour high values	Linear
Infrastructural development:		
Urban-related buildings and infrastructure per km^2 (1990)	Favour high values	Linear
Urban-related buildings and infrastructure per km^2 (2020)	Favour high values	Linear
Urban-related infrastructural development:		
Historical urban-related land cover/use (1990) per km^2	Favour high values	Linear
Present-day urban-related land cover/use (1990) per km^2	Favour high values	Linear
Informality:		
Informal dwellings and residential areas per km^2 (1990)	Favour high values	Linear
Informal dwellings and residential areas per km^2 (2020)	Favour high values	Linear

Appendix 10: Fuzzy overlay approach for the analysis of post-mining landscape characteristics from local experts

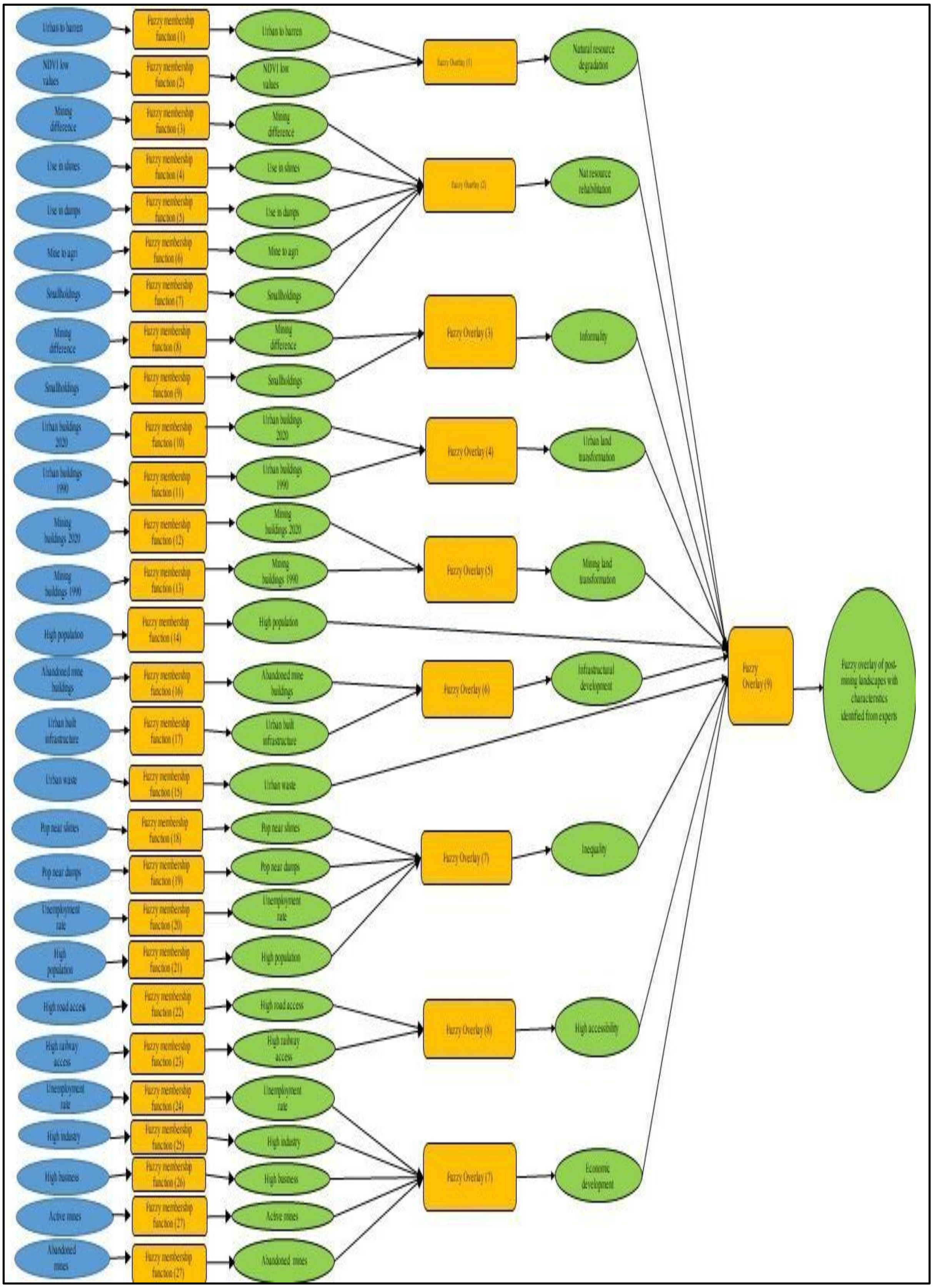
CHARACTERISTIC	APPROACH	REASON
Economic development and diversity:	OR	Allows the combination of businesses, industries, active mines, employment and abandoned mines per km^2.
High business count per km^2		
High industry count per km^2		
Active mines count per km^2		

Abandoned mines per km^2		
Low unemployment per km^2		
High population density:		No combination required
High population count per km^2		
Integrative rehabilitation and management:	OR	Allows the combination of the areal extent of post-mining land uses and development within dumps and slimes buffers.
Post-mining land uses per km^2		
Development within mine dumps buffer per km^2		
Development within slimes buffer per km^2		
Smallholdings per km^2		
Mines to agriculture per km^2		
Social impact:	OR	Allows the combination of the areal extent of the population proportion per km^2 within proximity of mine dumps and slimes, high unemployment and population per km^2.
Proportion of population within proximity of mine dumps per km^2		
Proportion of population within proximity of slimes per km^2		
High unemployment per km^2		
High population count per km^2		
Accessibility:	AND	'AND' is limiting, whereas 'OR' and 'GAMMA' over compensate. Also, post-mining landscapes have limited accessibility; therefore, 'AND' is the preferred operator as it returns the minimum value of the sets the cell location belongs to.
High road accessibility (within 500m) per km^2		
High railway accessibility (within 1000m) per km^2		
Abandoned mines and infrastructure:	OR	Allows the combination of the areal extent of both the abandoned mines and the mine buildings
Abandoned mines per km^2		
Mining-related buildings per km^2 (1990)		
Mining-related buildings per km^2 (2020)		
Mining-related land transformation:	AND	Allows the combination of all mining-related cover/use, even land rehabilitated and replaced by other non-mining uses.
Historical mining-related land cover/use per km^2 (1990)		
Present-day mining-related land cover/use per km^2 (2020)		
Natural resource use and degradation:	OR	Allows the combination of the areal extent of low NDVI values, mine waste and residue areas and land degraded to a barren or eroded state.
Low NDVI values per km^2		
Mine residue areas per km^2		
Mines to barren/eroded per km^2		
Urban to barren/eroded per km^2		
Waste per km^2		
Urban-related infrastructural development:	AND	Allows the combination of all urban-related buildings and infrastructure.
Urban-related buildings and infrastructure per km^2 (1990)		
Urban-related buildings and infrastructure per km^2 (2020)		
Informality:	AND	Allows the combination of all informal land cover/use.
Informal dwellings and residential areas per km^2 (1990)		
Informal dwellings and residential areas per km^2 (2020)		
Urban-related land transformation:	AND	Allows the combination of all urban-related cover/use, even land rehabilitated and replaced by other non-mining uses.
Historical urban-related land cover/use (1990) per km^2		
Present-day urban-related land cover/use (1990) per km^2		

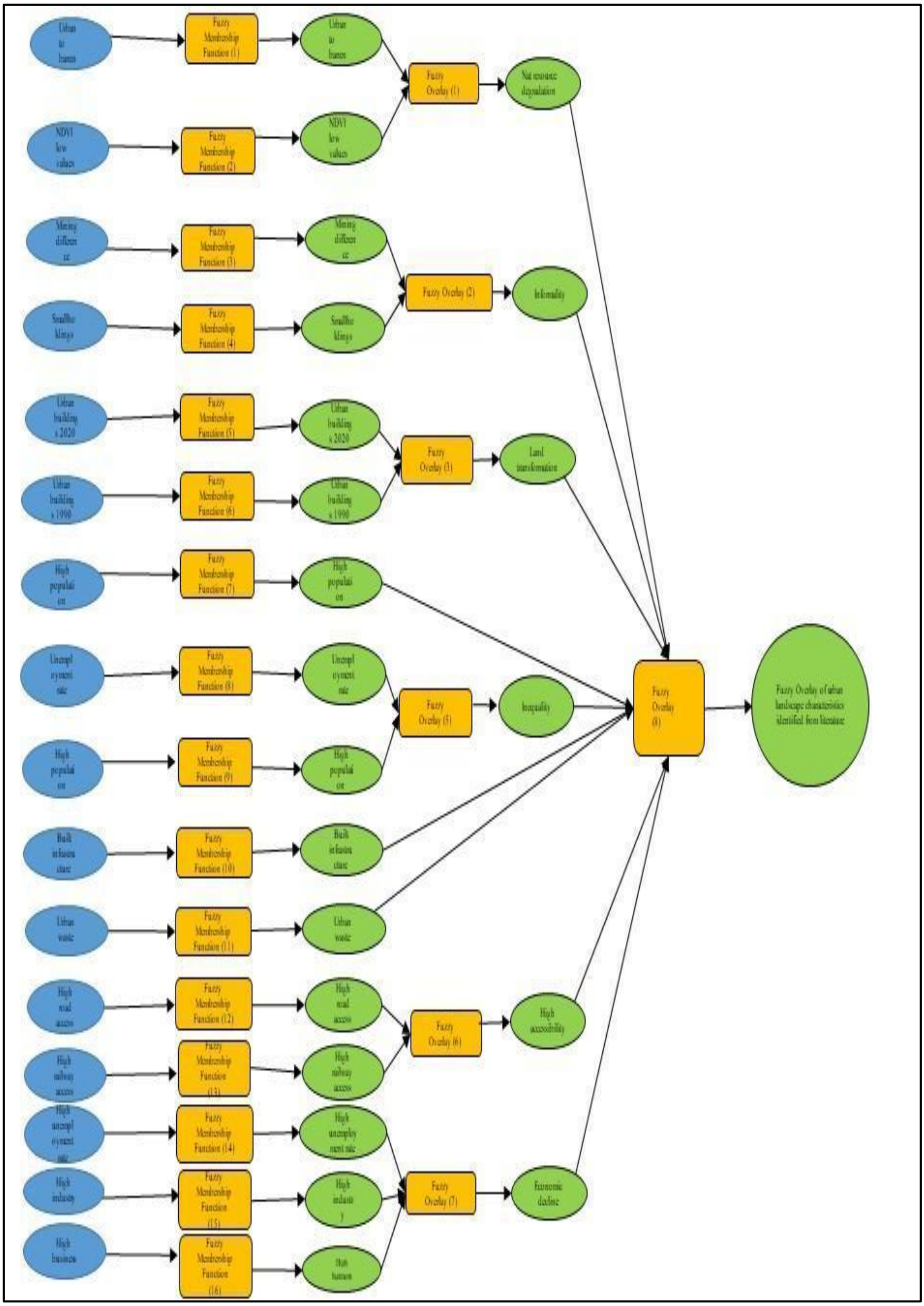
Appendix 11: Fuzzy membership map of the post-mining landscape characteristics from experts



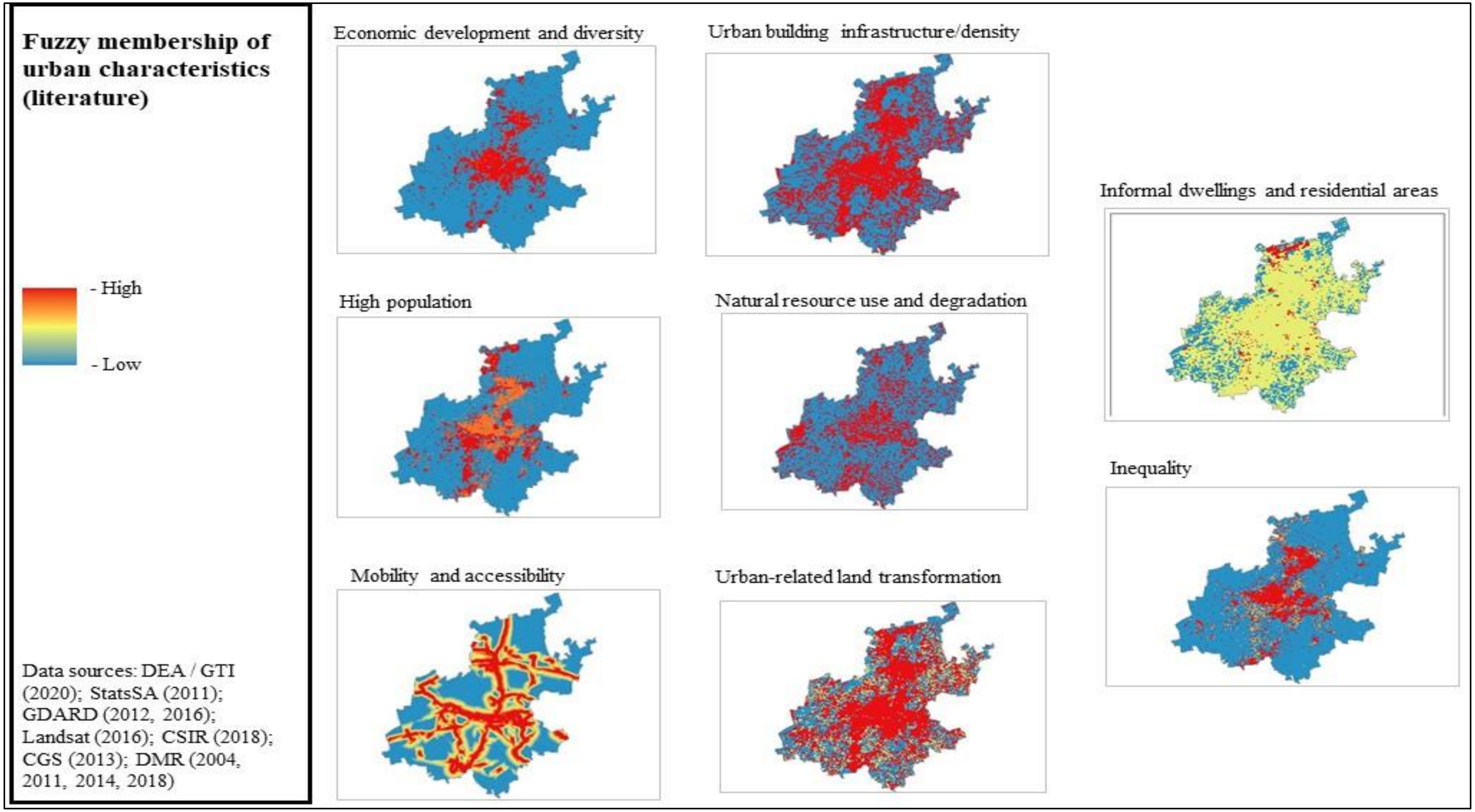
Appendix 12: Fuzzy overlay Arcmap model for the analysis of the post-mining landscape characteristics from experts



Appendix 13: Fuzzy overlay Arcmap model for the analysis of the urban landscape characteristics from literature



Appendix 14: Enlarged fuzzy membership map of the urban landscape characteristics from literature



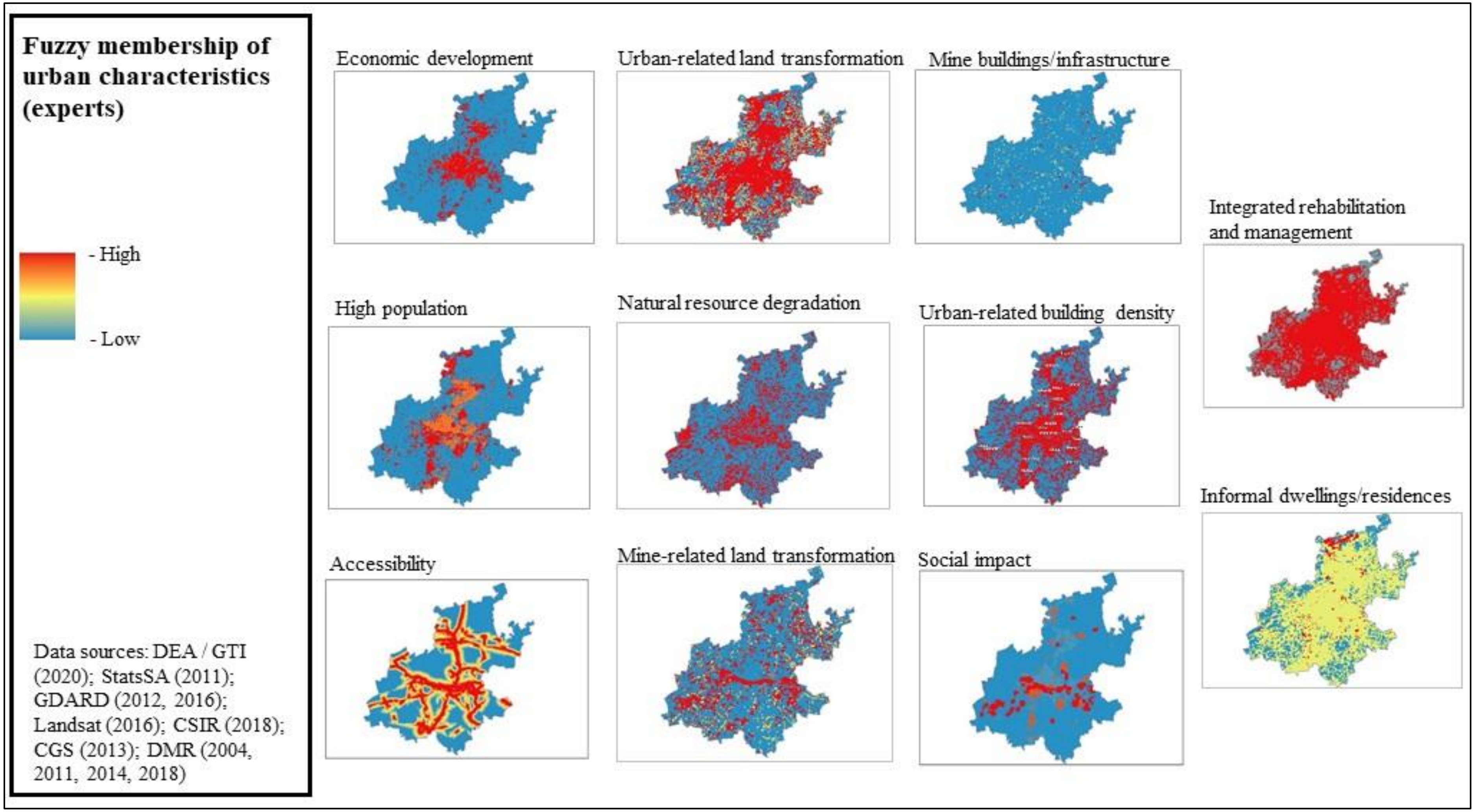
Appendix 15: Fuzzy membership of the urban landscape characteristics from experts

CRITERION	MEMBERSHIP	FUNCTION
Economic development and diversity:		
High business count per km^2	Favour high values	Linear
High industry count per km^2	Favour high values	Linear
Low unemployment rate per km^2	Favour high values	Linear
Active mines count per km^2	Favours high values	Linear
Abandoned mines per km^2	Favours high values	Linear
Mobility and accessibility:		
High railway accessibility (most favourable - within 1000m)	Favour high values	Linear
High road accessibility (most favourable - within 500m)	Favour high values	Linear
Population density:		
High population count per km^2	Favour high values	Linear
Social impact:		
High unemployment rate per km^2	Favour high values	Linear
High population density per km^2	Favour high values	Linear
Proportion of population within proximity of mine dumps per km^2	Favour high values	Linear
Proportion of population within proximity of slimes per km^2	Favour high values	Linear
Urban-related land transformation:		
Historical urban-related land cover/use (1990) per km^2	Favour high values	Linear
Present-day urban-related land cover/use (1990) per km^2	Favour high values	Linear
Urban infrastructural development:		
Urban-related buildings and infrastructure per km^2 (1990)	Favour high values	Linear
Urban-related buildings and infrastructure per km^2 (2020)	Favour high values	Linear
Informality:		
Informal dwellings and residential areas per km^2 (1990) per km^2	Favour high values	Linear
Informal dwellings and residential areas per km^2 (2020) per km^2	Favour high values	Linear
Natural resource use and degradation:		
NDVI low values per km^2	Favour high values	Linear
Urban to barren/eroded per km^2	Favour high values	Linear
Mine residue areas per km^2	Favour high values	Linear
Mines to barren/eroded per km^2	Favour high values	Linear
Waste per km^2	Favour high values	Linear
Mining-related land transformation:		
Historical mining-related land cover/use (1990) per km^2	Favour high values	Linear
Present-day mining-related land cover/use (2020) per km^2	Favour high values	Linear
Integrative rehabilitation and management:		
Post-mining land uses per km^2	Favours high values	Linear
Development within mine dumps buffer per km^2	Favours high values	Linear
Development within slimes buffer per km^2	Favours high values	Linear
Smallholdings per km^2	Favours high values	Linear
Mines to agriculture per km^2	Favours high values	Linear
Abandoned mine infrastructure and buildings:		
Mine-related buildings per km^2 (1990)	Favours high values	Linear
Mine-related buildings per km^2 (2020)	Favours high values	Linear

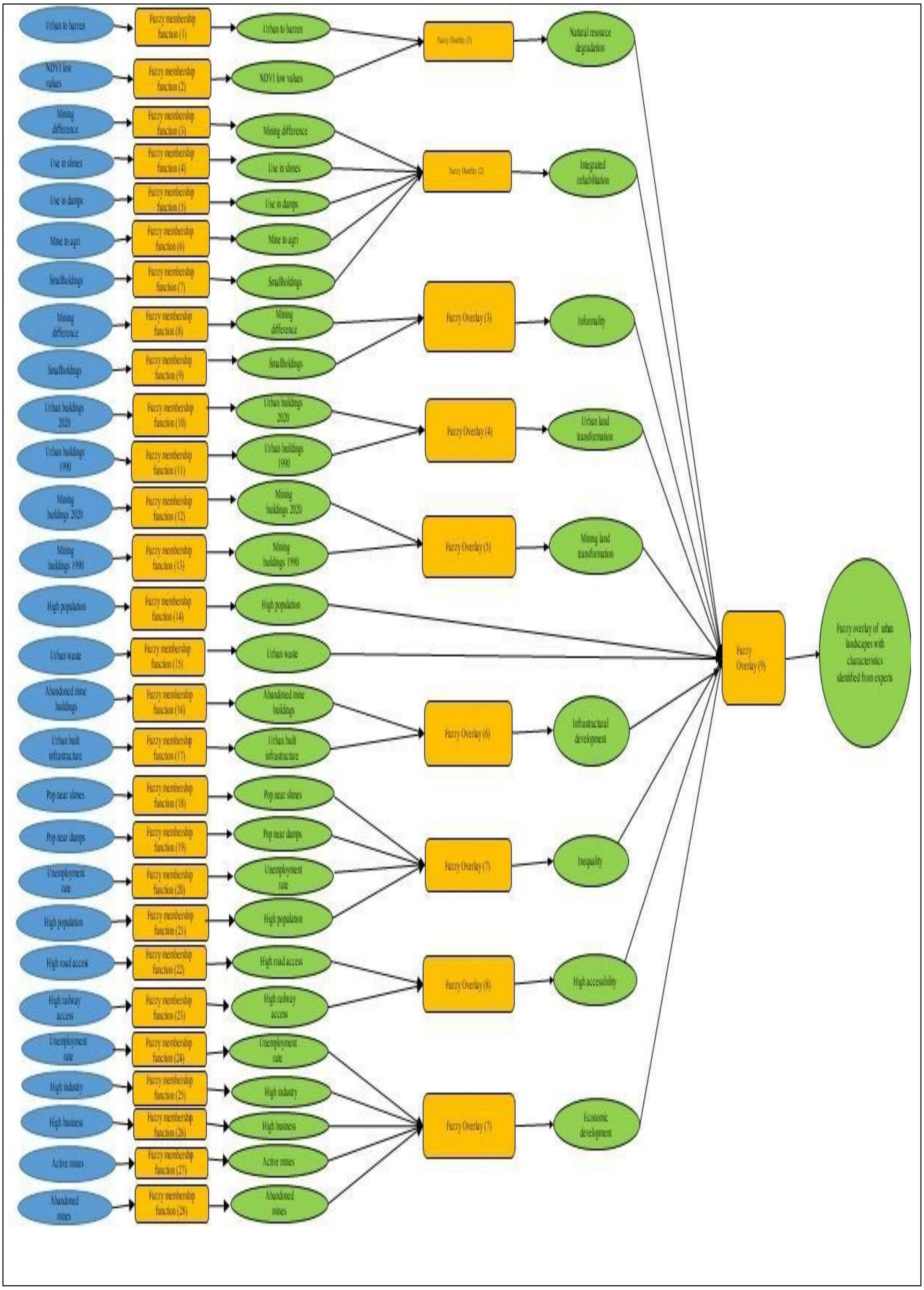
Appendix 16: Fuzzy approach for the analysis of urban landscape characteristics from experts

CHARACTERISTIC	APPROACH	REASON
Economic opportunities and diversity:	OR	Allows the combination of industries and businesses.
High business count per km^2		
High industry count per km^2		
Low unemployment rate per km^2		
Active mines count per km^2		
Abandoned mines per km^2		
Mobility and accessibility:	AND	Overcompensates access as urban areas are supposedly encouraging mobility and accessibility.
High railway accessibility (most favourable - within 1000m)		
High road accessibility (most favourable - within 500m)		
Population density:		No combination required
High population count per km^2		
Urban-related land transformation:	AND	Allows the combination of all urban-related cover/use, even land rehabilitated and replaced by other non-mining uses.
Historical urban-related land cover/use (1990) per km^2		
Present-day urban-related land cover/use (1990) per km^2		
Urban infrastructural development:	AND	Allows the combination of all urban-related buildings and infrastructure.
Urban-related buildings and infrastructure per km^2 (1990)		
Urban-related buildings and infrastructure per km^2 (2020)		
Informality:	AND	Allows the combination of all informal-related cover/use.
Informal dwellings and residential areas per km2 (1990)		
Informal dwellings and residential areas per km2 (2020)		
Natural resource use and degradation:	OR	Allows the combination of areas characterised by low NDVI values and those areas that urban land uses have degraded
Low NDVI values per km^2		
Urban to barren/eroded per km^2		
Mines to barren/eroded per km^2		
Mine waste and residue per km^2		
Waste per km^2		
Integrated rehabilitation and management:	OR	Allows the combination of the areal extent of post-mining land uses and development within dumps and slimes buffers.
Post-mining land uses per km^2		
Development within mine dumps buffer per km^2		
Development within slimes buffer per km^2		
Mines to agriculture per km^2		
Smallholdings per km^2		
Social impact:	OR	Allows the combination of the areal extent of the population proportion per km^2 within proximity of mine dumps and slimes, high unemployment and population per km^2.
Population near slimes per km^2		
Population near dumps per km^2		
Low unemployment per km^2		
High population density per km^2		
Abandoned mine infrastructure and buildings:	AND	Allows the combination of all mining-related built infrastructure.
Mine-related buildings per km^2 (1990)		
Mine-related buildings per km^2 (2020)		
Mining-related land transformation:	AND	Allows the combination of all mining-related cover/use, even land that has been rehabilitated and replaced by other non-mining uses.
Mining-related land use (1990) per km^2		
Mining-related land use 2020 per km^2		

Appendix 17: Fuzzy membership of urban landscape characteristics from experts



Appendix 18: Fuzzy overlay Arcmap model for the analysis of the urban landscape characteristics from experts



Appendix 19: Weighted overlay Arcmap model for the analysis of the post-mining landscape characteristics from literature

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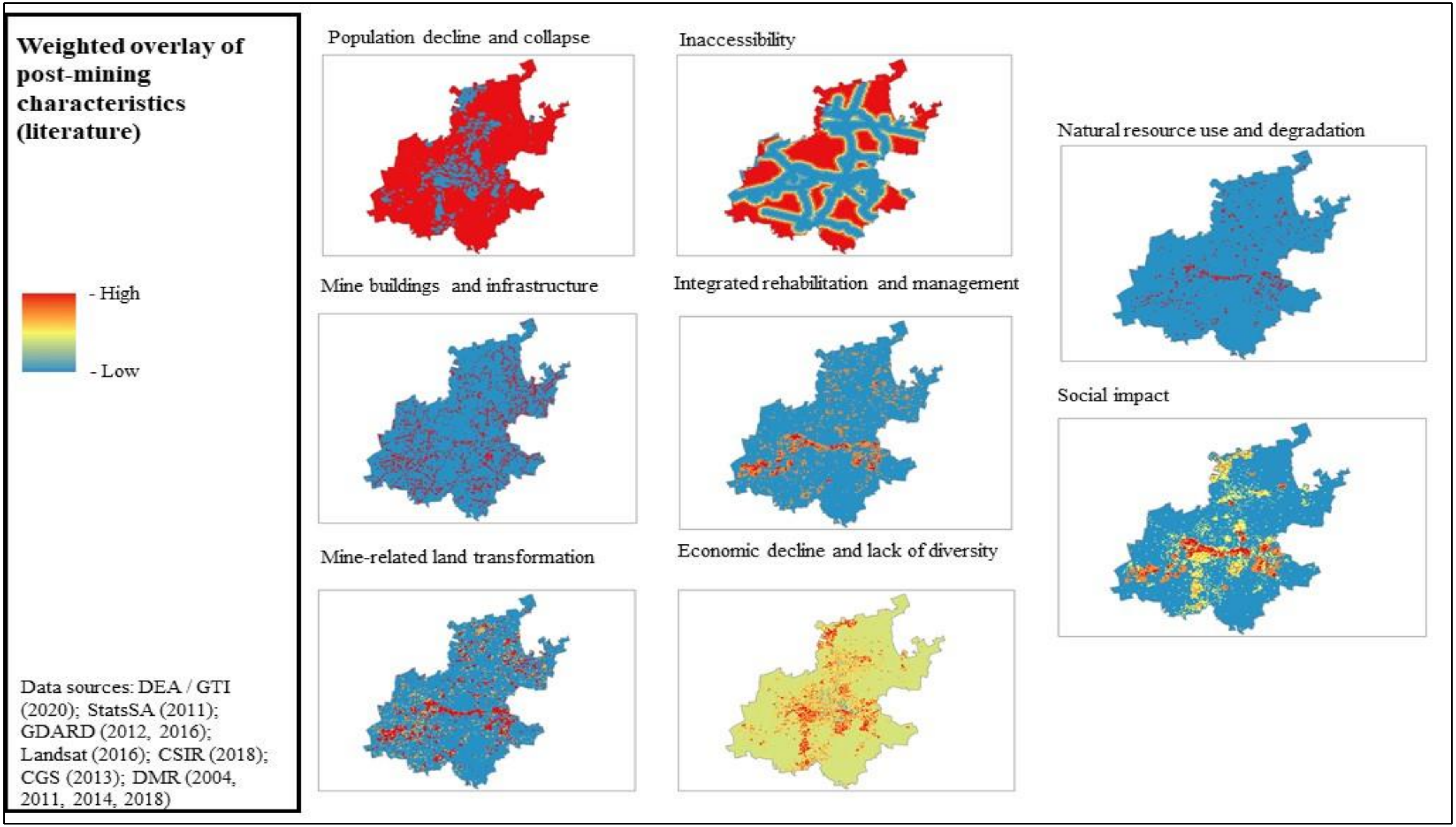
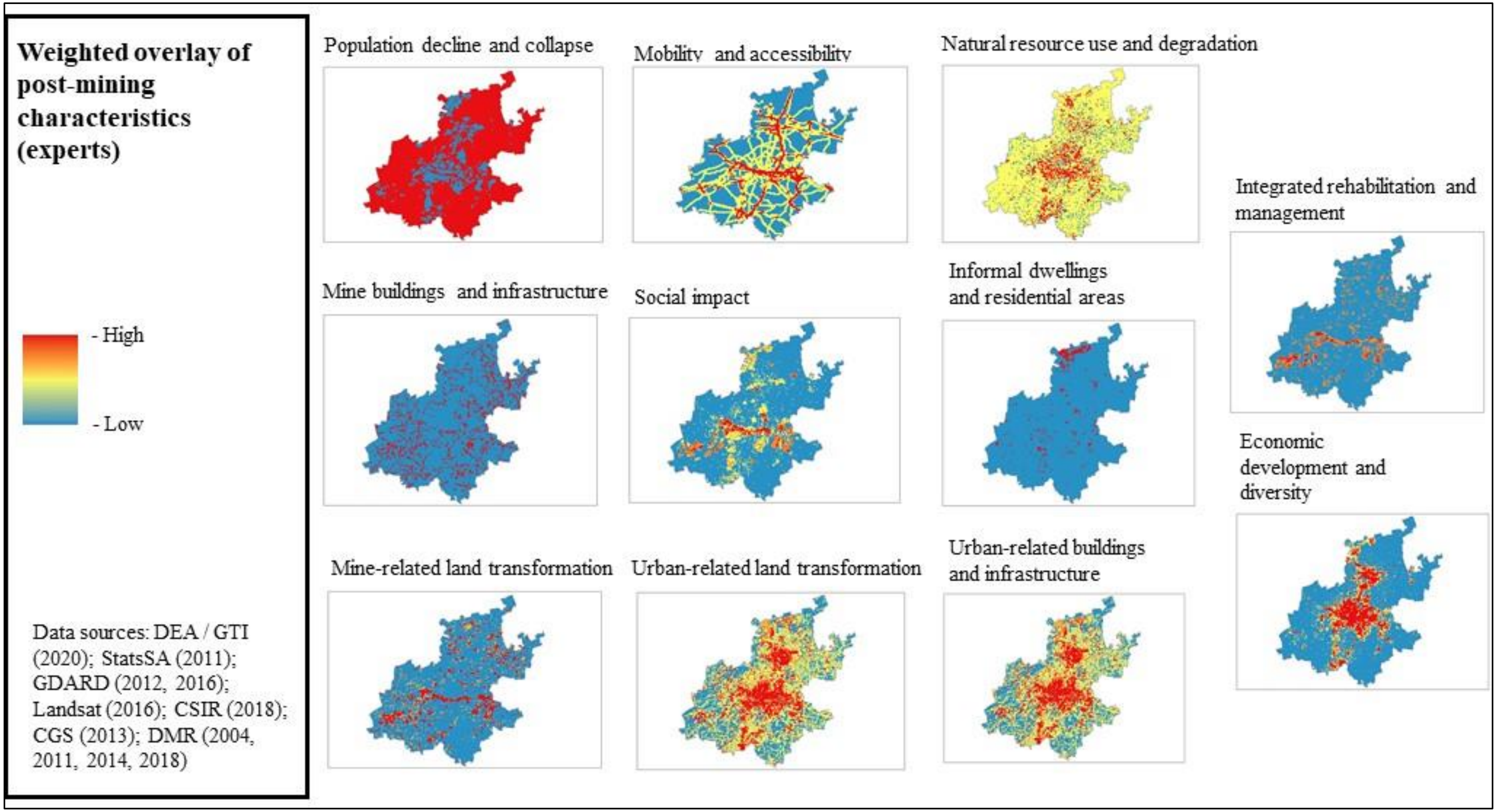
Appendix 20: Enlarged weighted overlay variable map of the post-mining landscape characteristics from literature



Appendix 21: Weighted overlay criteria of the post-mining landscape characteristics from experts

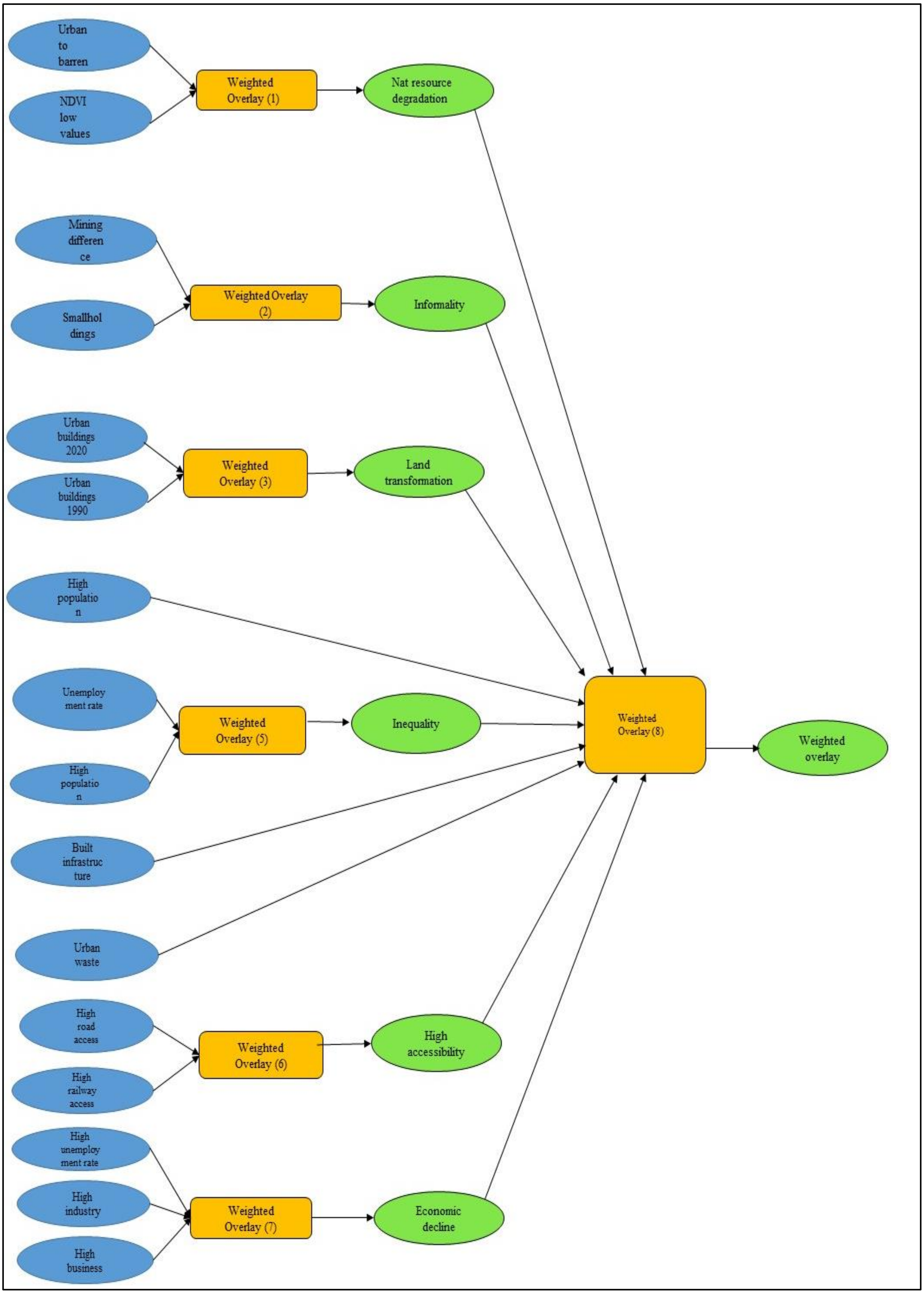
WEIGHTED OVERLAY VARIABLES	WEIGHTED OVERLAY CRITERIA	INFLUENCE %	WEIGHTED OVERLAY VARIABLES	VARIABLE INFLUENCE %
Natural resource use and degradation	NDVI low values per km^2	20	100	9
	Mines to barren/eroded per km^2	20		
	Mine waste and residue per km^2	20		
	Urban to barren/eroded per km^2	20		
	Waste per km^2	20		
Integrated rehabilitation and management	Post-mining land uses per km^2	20	100	9
	Development and use in slimes per km^2	20		
	Development and use in dumps per km^2	20		
	Mines to agriculture per km^2	20		
	Smallholdings per km^2	20		
Mining-related land transformation	Mining-related land use (1990) per km^2	50	100	10
	Mining-related land use (2020) per km^2	50		
Economic development and decline	High business count per km2 per km^2	20	100	9
	High industry count per km2 per km^2	20		
	Abandoned mines per km^2	20		
	Active mines per km^2	20		
	Low unemployment rate per km^2	20		
Social impact	Population near slimes per km^2	25	100	9
	Population near dumps per km^2	25		
	High unemployment per km^2	25		
	High population density per km^2	25		
High population	High population count per km^2	100	100	9
High accessibility	High road accessibility per km^2	50	100	9
	High railway accessibility per km^2	50		
Abandoned mine infrastructure and buildings	Mine-related buildings per km^2	100	100	9
Urban-related land transformation	Historical urban-related land cover/use (1990) per km^2	50	100	9
	Present-day urban-related land cover/use (1990) per km^2	50		
Urban built infrastructure	Urban-related buildings and infrastructure (1990) per km^2	50	100	9
	Urban-related buildings and infrastructure (2020) per km^2	50		
Informality	Informal dwellings and residential areas (1990) per km^2	50	100	9
	Informal dwellings and residential areas (2020) per km^2	50		
				100%

Appendix 22: Weighted overlay variable map of the post-mining landscape characteristics from experts

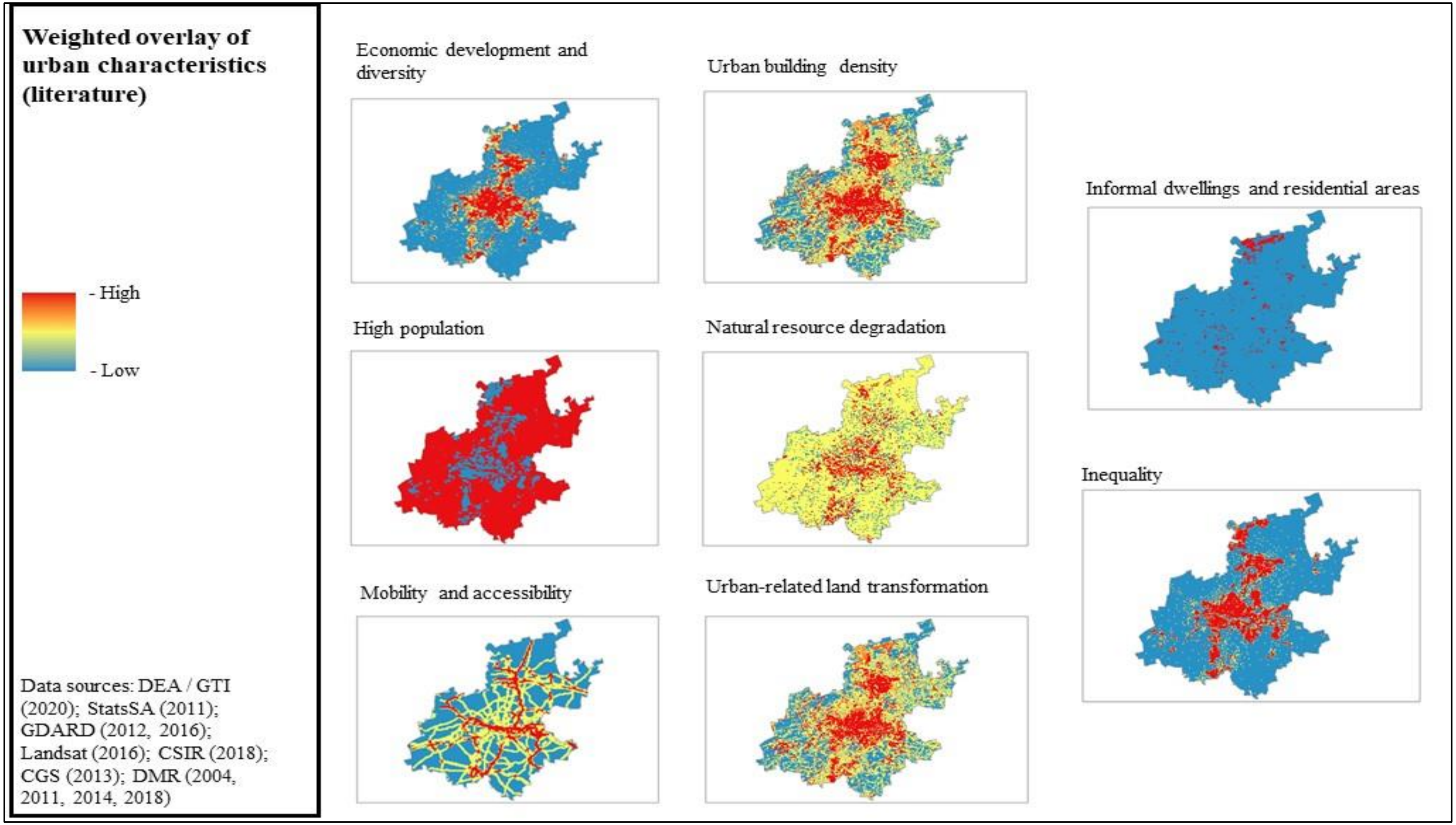


Appendix 23: Weighted overlay Arcmap model for the analysis of the post-mining landscape characteristics from experts

Appendix 24: Weighted overlay Arcmap model for the analysis of the urban landscape characteristics from literature



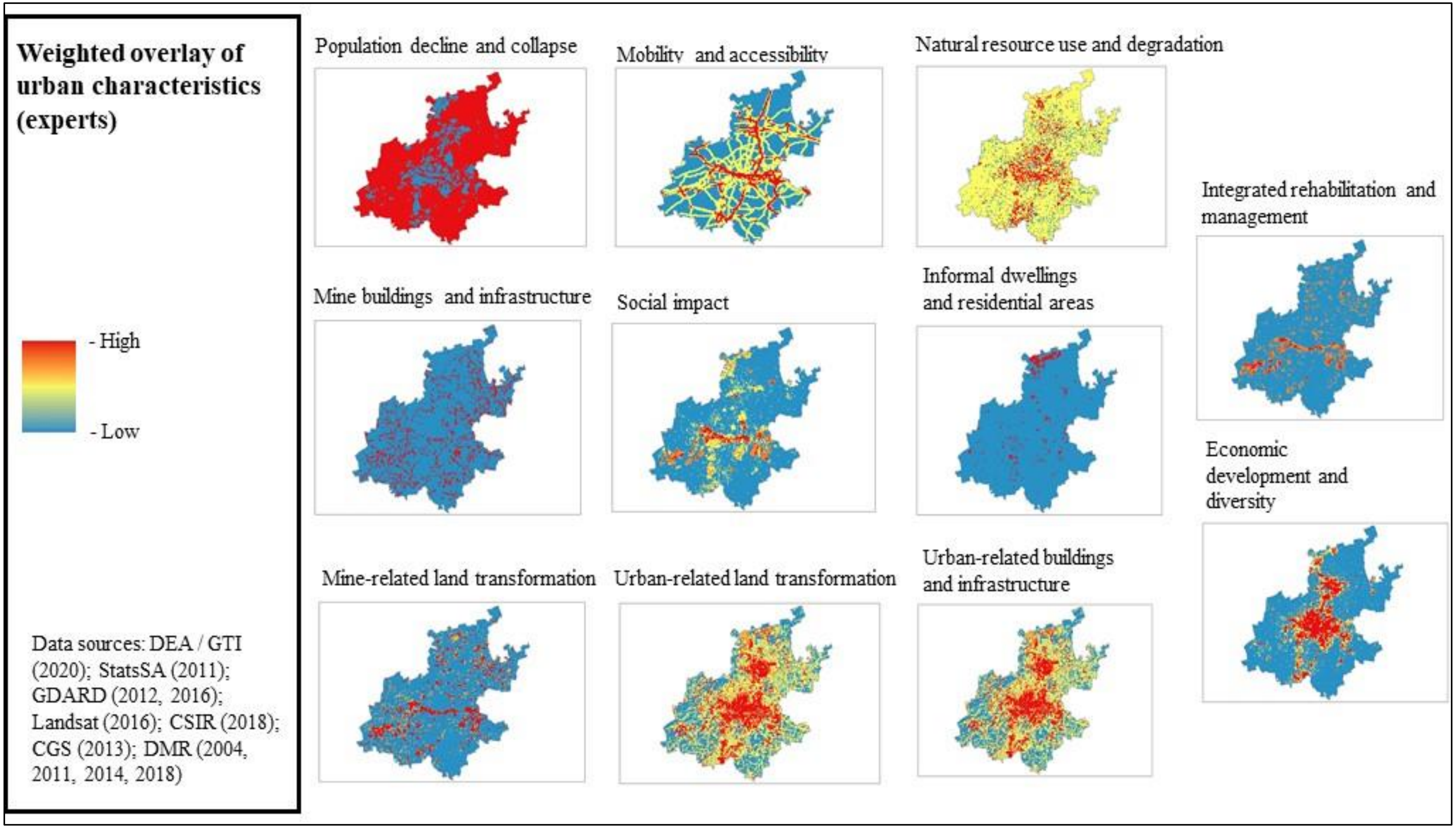
Appendix 25*: Enlarged weighted overlay map of criteria for the analysis of the urban landscape characteristics from literature*



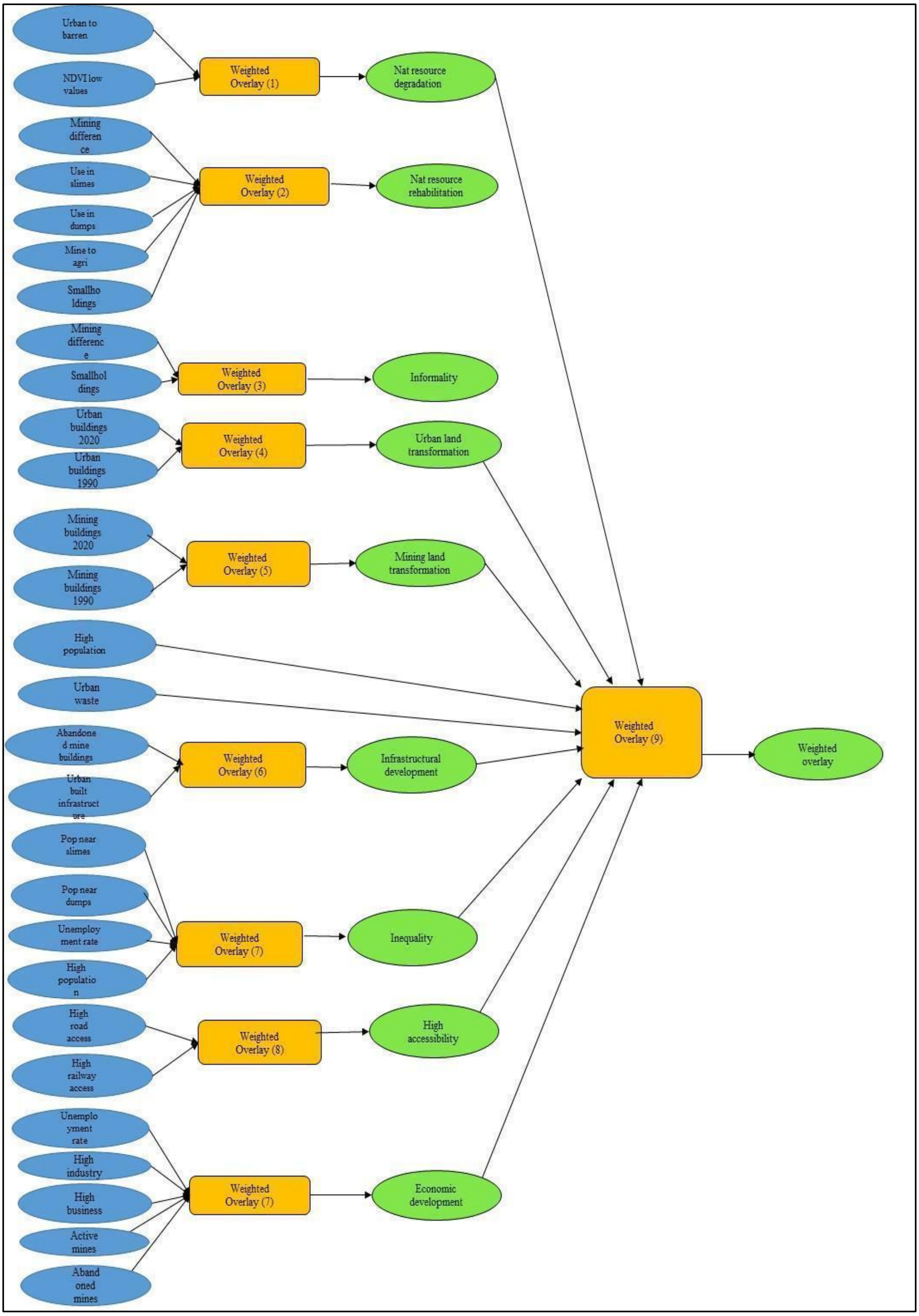
Appendix 26: Weighted overlay criteria for the analysis of the urban landscape characteristics from experts

WEIGHTED OVERLAY VARIABLES	WEIGHTED OVERLAY CRITERIA	INFLUENCE WEIGHTING %	WEIGHTED OVERLAY	OVERALL INFLUENCE WEIGHTING %
Urban-related land transformation	Urban-related land use 1990 per km^2	50	100	9
	Urban-related land use 2020 per km^2	50		
Economic development	High business per km^2	20	100	10
	High industry per km^2	20		
	Low unemployment per km^2	20		
	Active mines per km^2	20		
	Abandoned mines per km^2	20		
High population density	High population per km^2	100	100	9
Accessibility	Roads within 500m per km^2	50	100	9
	Railway within 1000 per km^2	50		
Urban-related built infrastructure	Urban related-buildings and infrastructure(1990) per km^2	50	100	9
	Urban related-buildings and infrastructure (2020) per km^2	50		
Informality	Informal dwellings and residential areas (1990) per km^2	50	100	9
	Informal dwelling and residential areas (2020) per km^2	50		
Natural resource use and degradation	Low NDVI values per km^2	20	100	9
	Mines to barren/eroded per km^2	20		
	Mine waste and residue per km^2	20		
	Urban to barren/eroded per km^2	20		
	Waste per km^2	20		
Integrated rehabilitation and management	Post-mining land use per km^2	20	100	9
	Development and use in slimes per km^2	20		
	Development and use in dumps per km^2	20		
	Mines to agriculture per km^2	20		
	Smallholdings per km^2	20		
Social impact	Population near slimes per km^2	25	100	9
	Population near dumps per km^2	25		
	High unemployment per km^2	25		
	High population density per km^2	25		
Mining-related land transformation	Mining-related land use (1990) per km^2	50	100	9
	Mining-related land use (2020) per km^2	50		
Mining built infrastructure	Mining related-buildings and infrastructure (1990) per km^2	50	100	9
	Mining related-buildings and infrastructure (2020) per km^2	50		
				100%

Appendix 27: Weighted overlay map of variables of the urban landscape characteristics from experts



Appendix 28: Weighted overlay Arcmap model for the analysis of the urban landscape characteristics from experts



Appendix 29: Predictor variables used for the random forest classification of the post-mining landscape characteristics from local experts

CATEGORY	PREDICTOR VARIABLE	TYPE
Natural resource use and degradation	Low NDVI values per km^2	Binary
	Mines to barren/eroded per km^2	Binary
	Mine waste and residue per km^2	Binary
	Urban to barren/eroded per km^2	Binary
	Waste per km^2	Binary
Integrated rehabilitation and management	Post-mining land uses per km^2	Binary
	Development and use in slimes per km^2	Binary
	Development and use in dumps per km^2	Binary
	Mines to agricultural land per km^2	Binary
	Smallholdings 1990 per km^2	Binary
	Smallholdings 2020 per km^2	Binary
Mining-related land transformation	Mining-related land use 1990 per km^2	Binary
	Mining-related land use 2020 per km^2	Binary
Economic development	High business per km^2	Binary
	High industry per km^2	Binary
	Abandoned mines per km^2	Binary
	Active mines per km^2	Binary
	Low unemployment per km^2	Binary
Social impact	Population near slimes per km^2	Binary
	Population near dumps per km^2	Binary
	High unemployment per km^2	Binary
	High population density per km^2	Binary
High population	Low population per km^2	Binary
Accessibility	Roads (within 500m) per km^2	Binary
	Railway (within 1000m) per km^2	Binary
Abandoned mine infrastructure and buildings	Mining related-buildings and infrastructure (1990) per km^2	Binary
	Mining related-buildings and infrastructure (2020) per km^2	Binary
Urban built infrastructure	Urban related-buildings and infrastructure(1990) per km^2	Binary
	Urban related-buildings and infrastructure (2020) per km^2	Binary
Urban-related land transformation	Urban-related land use (1990) per km^2	Binary
	Urban-related land use (2020) per km^2	Binary
Informality	Informal dwellings and residential areas (1990) per km^2	Binary
	Informal dwelling and residential areas (2020) per km^2	Binary

Appendix 30: Random forest classification script: post-mining landscape characteristics

```
install.packages("caret", dependencies = TRUE)

install.packages("randomForest")


library(caret)

library(randomForest)
```

```
install.packages("e1071")

library(e1071)


install.packages("prediction")

library(prediction)


install.packages("writexl")

library(writexl)

####################################################################################

#POST-MINING LITERATURE

####################################################################################

miningtest  <-  read.csv('C:\\Users\\Desktop\\Decisiontree\\miningtest.csv',  sep  =  ";", header=TRUE)

miningtrain  <-  read.csv('C:\\Users\\Desktop\\Decisiontree\\miningtrain.csv',  sep  =  ";", header=TRUE)


head(miningtrain)

head(miningtest)


# Converting 'Classification' to a factor

miningtrain$Classification <- factor(miningtrain$Classification)


# Set a random seed

set.seed(51)


# Define the control

trControl <-trainControl(method = "cv",

number = 10,

search = "grid")


# Run the model

rf_pmining <- train(Classification ~ Lowbusiness + Lowindustry + Activemines + Abandonedmines + Lowpopulation + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps +  Lowrailaccess  +  Lowroadaccess  +  Minebuildingsandinfra  +  Min90trans  +  Min20trans +Degradedndvi + Mra + Degradedminestobarren,

  data = miningtrain,

  method = "rf",

  metric = "Accuracy",

  trControl = trControl)
```

```
# Print the results
print(rf_pmining)

set.seed(1234)
tuneGrid <- expand.grid(.mtry = c(1: 10))
rf_mtry <- train(Classification ~ Lowbusiness + Lowindustry + Activemines + Abandonedmines
+ Lowpopulation + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps
+ Lowrailaccess + Lowroadaccess + Minebuildingsandinfra + Min90trans + Min20trans
+Degradedndvi + Mra + Degradedminestobarren,
  data = miningtrain,
  method = "rf",
  metric = "Accuracy",
  tuneGrid = tuneGrid,
  trControl = trControl,
  importance = TRUE,
  nodesise = 14,
  ntree = 300)
print(rf_mtry)

best_mtry <- rf_mtry$bestTune$mtry
best_mtry

store_maxnode <- list()
tuneGrid <- expand.grid(.mtry = best_mtry)
for (maxnodes in c(5: 15)) {
 set.seed(1234)
 rf_maxnode <- train(Classification ~ Lowbusiness + Lowindustry + Activemines +
Abandonedmines + Lowpopulation + Postmininglandmindiff + Useinslimes + Useindumps +
Popinslimes + Popindumps + Lowrailaccess + Lowroadaccess + Minebuildingsandinfra + Min90trans
+ Min20trans +Degradedndvi + Mra + Degradedminestobarren,
   data = miningtrain,
   method = "rf",
   metric = "Accuracy",
   tuneGrid = tuneGrid,
   trControl = trControl,
   importance = TRUE,
   nodesise = 14,
   maxnodes = maxnodes,
   ntree = 300)
 current_iteration <- toString(maxnodes)
```

```
 store_maxnode[[current_iteration]] <- rf_maxnode

}

results_mtry <- resamples(store_maxnode)

summary(results_mtry)


store_maxtrees <- list()

for (ntree in c(250, 300, 350, 400, 450, 500, 550, 600, 800, 1000, 2000)) {

 set.seed(5678)

 rf_maxtrees <- train(Classification ~ Lowbusiness + Lowindustry + Activemines + Abandonedmines + Lowpopulation + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps + Lowrailaccess + Lowroadaccess + Minebuildingsandinfra + Min90trans + Min20trans +Degradedndvi + Mra + Degradedminestobarren,

   data = miningtrain,

   method = "rf",

   metric = "Accuracy",

   tuneGrid = tuneGrid,

   trControl = trControl,

   importance = TRUE,

   nodesise = 14,

   maxnodes = 24,

   ntree = ntree)

 key <- toString(ntree)

 store_maxtrees[[key]] <- rf_maxtrees

}

results_tree <- resamples(store_maxtrees)

summary(results_tree)


fit_pminingf <- train(Classification ~ Lowbusiness + Lowindustry + Activemines + Abandonedmines + Lowpopulation + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps + Lowrailaccess + Lowroadaccess + Minebuildingsandinfra + Min90trans + Min20trans +Degradedndvi + Mra + Degradedminestobarren,

  data = miningtrain,

  method = "rf",

  metric = "Accuracy",

  tuneGrid = tuneGrid,

  trControl = trControl,

  importance = TRUE,

  nodesise = 14,

  ntree = 800,
```

```
  maxnodes = 24)

miningtest$Classification <-predict(fit_pminingf, miningtest)

varImp(fit_pminingf)

confusionMatrix(fit_pminingf, miningtest$Classification)

df <-data.frame(miningtest)
print(df)

write_xlsx(miningtest,"C:/Users/a0036293/Desktop/Decisiontree/pmininglit.xlsx")

################################################################################
#POST-MINING EXPERTS
################################################################################
expertminingtest <- read.csv('C:\\Users\\Desktop\\Decisiontree\\expertminingtest1.csv', sep
= ";", header=TRUE)
expertminingtrain  <-  read.csv('C:\\Users\\Desktop\\Decisiontree\\expertminingtrain1.csv',
sep = ";", header=TRUE)

head(expertminingtrain)
head(expertminingtest)

# Converting ‘Classification’ to a factor
expertminingtrain$Classification <- factor(expertminingtrain$Classification)

# Set a random seed
set.seed(51)

# Define the control
trControl <-trainControl(method = "cv",
   number = 10,
   search = "grid")

# Run the model
rf_expertpmining <- train(Classification ~ Highbus + Highind + Lowunemp + Highunemployment
+Activemines + Abandonedmines + Highpop + Postmininglandmindiff + Useinslimes + Useindumps
+ Popinslimes + Popindumps + Highrailaccess + Highroadaccess + Minebuildingsandinfra +
Min90trans + Min20trans +Degradedndvi + Mra + Degradedminestobarren + Urbbuiltinfra +
Smallholdings20 + Smallholdings90 + Minestoagri + Urb90trans + Urb20trans,
  data = expertminingtrain,
```

```
  method = "rf",
  metric = "Accuracy",
  trControl = trControl)
# Print the results
print(rf_expertpmining)

set.seed(1234)
tuneGrid <- expand.grid(.mtry = c(1: 10))
rf_mtry <- train(Classification ~ Highbus + Highind + Lowunemp + Highunemployment +Activemines + Abandonedmines + Highpop + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps + Highrailaccess + Highroadaccess + Minebuildingsandinfra + Min90trans + Min20trans +Degradedndvi + Mra + Degradedminestobarren + Urbbuiltinfra + Smallholdings20 + Smallholdings90 + Minestoagri+ Urb90trans + Urb20trans,
  data = expertminingtrain,
  method = "rf",
  metric = "Accuracy",
  tuneGrid = tuneGrid,
  trControl = trControl,
  importance = TRUE,
  nodesise = 14,
  ntree = 300)
print(rf_mtry)

best_mtry <- rf_mtry$bestTune$mtry
best_mtry

store_maxnode <- list()
tuneGrid <- expand.grid(.mtry = best_mtry)
for (maxnodes in c(5: 15)) {
 set.seed(1234)
 rf_maxnode <- train(Classification ~ Highbus + Highind + Lowunemp + Highunemployment +Activemines + Abandonedmines + Highpop + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps + Highrailaccess + Highroadaccess + Minebuildingsandinfra + Min90trans + Min20trans +Degradedndvi + Mra + Degradedminestobarren + Urbbuiltinfra + Smallholdings20 + Smallholdings90 + Minestoagri+ Urb90trans + Urb20trans,
   data = expertminingtrain,
   method = "rf",
   metric = "Accuracy",
   tuneGrid = tuneGrid,
   trControl = trControl,
```

```
   importance = TRUE,
   nodesise = 14,
   maxnodes = maxnodes,
   ntree = 300)
 current_iteration <- toString(maxnodes)
 store_maxnode[[current_iteration]] <- rf_maxnode
}
results_mtry <- resamples(store_maxnode)
summary(results_mtry)

store_maxtrees <- list()
for (ntree in c(250, 300, 350, 400, 450, 500, 550, 600, 800, 1000, 2000)) {
 set.seed(5678)
 rf_maxtrees <- train(Classification ~ Highbus + Highind + Lowunemp + Highunemployment
+Activemines + Abandonedmines + Highpop + Postmininglandmindiff + Useinslimes + Useindumps
+ Popinslimes + Popindumps + Highrailaccess + Highroadaccess + Minebuildingsandinfra +
Min90trans + Min20trans +Degradedndvi + Mra + Degradedminestobarren + Urbbuiltinfra +
Smallholdings20 + Smallholdings90 + Minestoagri+ Urb90trans + Urb20trans,
   data = expertminingtrain,
   method = "rf",
   metric = "Accuracy",
   tuneGrid = tuneGrid,
   trControl = trControl,
   importance = TRUE,
   nodesise = 14,
   maxnodes = 24,
   ntree = ntree)
 key <- toString(ntree)
 store_maxtrees[[key]] <- rf_maxtrees
}
results_tree <- resamples(store_maxtrees)
summary(results_tree)

fit_expertpminingf <- train(Classification ~ Highbus + Highind + Lowunemp + Highunemployment
+Activemines + Abandonedmines + Highpop + Postmininglandmindiff + Useinslimes + Useindumps
+ Popinslimes + Popindumps + Highrailaccess + Highroadaccess + Minebuildingsandinfra +
Min90trans + Min20trans +Degradedndvi + Mra + Degradedminestobarren + Urbbuiltinfra +
Smallholdings20 + Smallholdings90 + Minestoagri+ Urb90trans + Urb20trans,
   data = expertminingtrain,
   method = "rf",
```

```
    metric = "Accuracy",
    tuneGrid = tuneGrid,
    trControl = trControl,
    importance = TRUE,
    nodesise = 14,
    ntree = 800,
    maxnodes = 24)

expertminingtest$Classification <-predict(fit_expertpminingf, expertminingtest)

varImp(fit_expertpminingf)

confusionMatrix(fit_expertpminingf, expertminingtest$Classification)

df <-data.frame(expertminingtest)
print(df)

write_xlsx(expertminingtest,"C:/Users/Desktop/Decisiontree/pminingexpert.xlsx")
```

Appendix 31: Predictor variables used for the random forest classification of the urban landscape characteristics from experts

CATEGORY	PREDICTOR VARIABLE	TYPE
Economic development and diversity	High business per km^2	Binary
	High industry per km^2	Binary
	Low unemployment per km^2	Binary
	Active mines per km^2	Binary
	Abandoned mines per km^2	Binary
High population density	High population per km^2	Binary
Accessibility	Roads within 500m per km^2	Binary
	Railway within 1000m per km^2	Binary
Urban-related built infrastructure	Urban related-buildings and infrastructure(1990) per km^2	Binary
	Urban related-buildings and infrastructure (2020) per km^2	Binary
Urban-related land transformation	Urban-related land use (1990) per km^2	Binary
	Urban-related land use (2020) per km^2	Binary
Informality	Informal dwellings and residential areas (1990) per km^2	Binary
	Informal dwelling and residential areas (2020) per km^2	Binary
Urban waste	Waste per km^2	Binary
Natural resource use and degradation	NDVI low values per km^2	Binary
	Mines to barren/eroded per km^2	Binary
	Mine waste and residue per km^2	Binary

	Urban to barren/eroded per km^2	Binary
Integrated rehabilitation and management	Post-mining land uses per km^2	Binary
	Development and use in slimes per km^2	Binary
	Development and use in dumps per km^2	Binary
	Mines to agricultural land per km^2	Binary
	Smallholdings per km^2	Binary
Social impact	Population near slimes per km^2	Binary
	Population near dumps per km^2	Binary
	High unemployment per km^2	Binary
	High population density per km^2	Binary
Abandoned mine infrastructure and buildings	Mining related-buildings and infrastructure (1990) per km^2	Binary
	Mining related-buildings and infrastructure (2020) per km^2	Binary
Mining-related land transformation	Mining-related land use (1990) per km^2	Binary
	Mining-related land use (2020) per km^2	Binary

Appendix 32: Random forest classification script: Urban landscape characteristics

```
####################################################################################
#URBAN LANDSCAPE LITERATURE
####################################################################################

urbtest <- read.csv('C:\\Users\\Desktop\\Decisiontree\\urbtest.csv', sep = ";", header=TRUE)
urbtrain <- read.csv('C:\\Users\\Desktop\\Decisiontree\\urbtrain.csv', sep = ";", header=TRUE)

head(urbtrain)
head(urbtest)

# Converting 'Classification' to a factor
urbtrain$Classification <- factor(urbtrain$Classification)

# Set a random seed
set.seed(51)

# Define the control
trControl1 <- trainControl(method = "cv",
   number = 10,
   search = "grid")
# Run the model
rf_Urb <- train(Classification~Highbus + Highind + Lowunemp + Highrailaccess + Highroadaccess + Highpop + Urb90trans + Urb20trans + Degradedndvi + Waste + Informal90 + Urbtobar + Informal20 + Urbbuiltinfra,
```

```
  data = urbtrain,
  method = "rf",
  metric = "Accuracy",
  trControl = trControl)
# Print the results
print(rf_Urb)

set.seed(1234)
tuneGrid <- expand.grid(.mtry = c(1: 10))
rf_mtry  <-  train(Classification~Highbus  +  Highind  +  Lowunemp  +  Highrailaccess  +
Highroadaccess + Highpop + Urb90trans + Urb20trans + Degradedndvi + Waste + Informal90 +
Urbtobar + Informal20 + Urbbuiltinfra,
  data = urbtrain,
  method = "rf",
  metric = "Accuracy",
  tuneGrid = tuneGrid,
  trControl = trControl,
  importance = TRUE,
  nodesise = 14,
  ntree = 300)
print(rf_mtry)

best_mtry <- rf_mtry$bestTune$mtry
best_mtry

store_maxnode <- list()
tuneGrid <- expand.grid(.mtry = best_mtry)
for (maxnodes in c(5: 15)) {
 set.seed(1234)
 rf_maxnode  <-  train(Classification~Highbus  +  Highind  +  Lowunemp  +  Highrailaccess  +
Highroadaccess + Highpop + Urb90trans + Urb20trans + Degradedndvi + Waste + Informal90 +
Urbtobar + Informal20 + Urbbuiltinfra,
   data = urbtrain,
   method = "rf",
   metric = "Accuracy",
   tuneGrid = tuneGrid,
   trControl = trControl,
   importance = TRUE,
   nodesise = 14,
```

```
   maxnodes = maxnodes,
   ntree = 300)
 current_iteration <- toString(maxnodes)
 store_maxnode[[current_iteration]] <- rf_maxnode
}
results_mtry <- resamples(store_maxnode)
summary(results_mtry)

store_maxtrees <- list()
for (ntree in c(250, 300, 350, 400, 450, 500, 550, 600, 800, 1000, 2000)) {
 set.seed(5678)
 rf_maxtrees  <-  train(Classification~Highbus  +  Highind  +  Lowunemp  +  Highrailaccess  +
Highroadaccess + Highpop + Urb90trans + Urb20trans + Degradedndvi + Waste + Informal90 +
Urbtobar + Informal20 + Urbbuiltinfra,
   data = urbtrain,
   method = "rf",
   metric = "Accuracy",
   tuneGrid = tuneGrid,
   trControl = trControl,
   importance = TRUE,
   nodesise = 14,
   maxnodes = 24,
   ntree = ntree)
 key <- toString(ntree)
 store_maxtrees[[key]] <- rf_maxtrees
}
results_tree <- resamples(store_maxtrees)
summary(results_tree)

fit_urbrf  <-  train(Classification~Highbus  +  Highind  +  Lowunemp  +  Highrailaccess  +
Highroadaccess + Highpop + Urb90trans + Urb20trans + Degradedndvi + Waste + Informal90 +
Urbtobar + Informal20 + Urbbuiltinfra,
  urbtrain,
  method = "rf",
  metric = "Accuracy",
  tuneGrid = tuneGrid,
  trControl = trControl,
  importance = TRUE,
```

```
  nodesise = 14,
  ntree = 800,
  maxnodes = 24)

install.packages("prediction")
library(prediction)

urbtest$Classification <-predict(fit_urbrf, urbtest)

confusionMatrix(fit_urbrf, urbtest$Classification)

varImp(fit_urbrf)

install.packages("writexl")
library(writexl)

df <-data.frame(urbtest)
print(df)

write_xlsx(urbtest,"C:/Users/Desktop/Decisiontree/urbanlit.xlsx")
#################################################################################
#URBAN LANDSCAPE EXPERT
#################################################################################
install.packages("caret", dependencies = TRUE)
install.packages("randomForest")

library(caret)
library(randomForest)

install.packages("e1071")
library(e1071)

experturbantest <- read.csv('C:\\Users\\Desktop\\Decisiontree\\experturbantest1.csv', sep = ";", header=TRUE)
experturbantrain <- read.csv('C:\\Users\\Desktop\\Decisiontree\\experturbantrain1.csv', sep = ";", header=TRUE)

head(experturbantrain)
head(experturbantest)

# Converting ‘Classification’ to a factor
```

```
experturbantrain$Classification <- factor(experturbantrain$Classification)

# Set a random seed

set.seed(51)

# Define the control

trControl <- trainControl(method = "cv",

   number = 10,

   search = "grid")

# Run the model

rf_expertUrb <- train(Classification~Highbus + Highind + Lowunemp + Highrailaccess + Highroadaccess + Highpop + Urb90trans + Urb20trans + Degradedndvi + Waste + Informal90 + Urbtobar + Informal20 + Urbbuiltinfra + Highunemployment + Activemines + Abandonedmines + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps + Minebuildingsandinfra + Min90trans + Min20trans + Mra + Degradedminestobarren + Smallholdings20 + Smallholdings90 + Minestoagri,

  data = experturbantrain,

  method = "rf",

  metric = "Accuracy",

  trControl = trControl)

# Print the results

print(rf_expertUrb)


set.seed(1234)

tuneGrid <- expand.grid(.mtry = c(1: 10))

rf_mtry <- train(Classification~Highbus + Highind + Lowunemp + Highrailaccess + Highroadaccess + Highpop + Urb90trans + Urb20trans + Degradedndvi + Waste + Informal90 + Urbtobar + Informal20 + Urbbuiltinfra + Highunemployment + Activemines + Abandonedmines + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps + Minebuildingsandinfra + Min90trans + Min20trans + Mra + Degradedminestobarren + Smallholdings20 + Smallholdings90 + Minestoagri,

  data = experturbantrain,

  method = "rf",

  metric = "Accuracy",

  tuneGrid = tuneGrid,

  trControl = trControl,

  importance = TRUE,

  nodesise = 14,

  ntree = 300)

print(rf_mtry)


best_mtry <- rf_mtry$bestTune$mtry
```

```
best_mtry

store_maxnode <- list()

tuneGrid <- expand.grid(.mtry = best_mtry)

for (maxnodes in c(5: 15)) {

 set.seed(1234)

 rf_maxnode <- train(Classification~Highbus + Highind + Lowunemp + Highrailaccess + Highroadaccess + Highpop + Urb90trans + Urb20trans + Degradedndvi + Waste + Informal90 + Urbtobar + Informal20 + Urbbuiltinfra + Highunemployment + Activemines + Abandonedmines + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps + Minebuildingsandinfra + Min90trans + Min20trans + Mra + Degradedminestobarren + Smallholdings20 + Smallholdings90 + Minestoagri,

   data = experturbantrain,

   method = "rf",

   metric = "Accuracy",

   tuneGrid = tuneGrid,

   trControl = trControl,

   importance = TRUE,

   nodesise = 14,

   maxnodes = maxnodes,

   ntree = 300)

 current_iteration <- toString(maxnodes)

 store_maxnode[[current_iteration]] <- rf_maxnode

}

results_mtry <- resamples(store_maxnode)

summary(results_mtry)

store_maxtrees <- list()

for (ntree in c(250, 300, 350, 400, 450, 500, 550, 600, 800, 1000, 2000)) {

 set.seed(5678)

 rf_maxtrees <- train(Classification~Highbus + Highind + Lowunemp + Highrailaccess + Highroadaccess + Highpop + Urb90trans + Urb20trans + Degradedndvi + Waste + Informal90 + Urbtobar + Informal20 + Urbbuiltinfra + Highunemployment + Activemines + Abandonedmines + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps + Minebuildingsandinfra + Min90trans + Min20trans + Mra + Degradedminestobarren + Smallholdings20 + Smallholdings90 + Minestoagri,

   data = experturbantrain,

   method = "rf",

   metric = "Accuracy",

   tuneGrid = tuneGrid,

   trControl = trControl,
```

```
    importance = TRUE,
    nodesise = 14,
    maxnodes = 24,
    ntree = ntree)
  key <- toString(ntree)
  store_maxtrees[[key]] <- rf_maxtrees
}
results_tree <- resamples(store_maxtrees)
summary(results_tree)

fit_experturbf <- train(Classification~Highbus + Highind + Lowunemp + Highrailaccess + Highroadaccess + Highpop + Urb90trans + Urb20trans + Degradedndvi + Waste + Informal90 + Urbtobar + Informal20 + Urbbuiltinfra + Highunemployment + Activemines + Abandonedmines + Postmininglandmindiff + Useinslimes + Useindumps + Popinslimes + Popindumps + Minebuildingsandinfra + Min90trans + Min20trans + Mra + Degradedminestobarren + Smallholdings20 + Smallholdings90 + Minestoagri,
   experturbantrain,
   method = "rf",
   metric = "Accuracy",
   tuneGrid = tuneGrid,
   trControl = trControl,
   importance = TRUE,
   nodesise = 14,
   ntree = 800,
   maxnodes = 24)

install.packages("prediction")
library(prediction)

experturbantest$Classification <-predict(fit_experturbf, experturbantest)

confusionMatrix(fit_experturbf, experturbantest$Classification)

varImp(fit_experturbf)

install.packages("writexl")
library(writexl)
df <-data.frame(experturbantest)
print(df)
write_xlsx(experturbantest,"C:/Users/Desktop/Decisiontree/urbanexpert.xlsx")
```

Appendix 33*: Post-mining landscape characteristics identified from literature*

POST-MINING LANDSCAPE CONCEPTS FROM LITERATURE		
Concept	**New concept allocation**	**Reason**
Anthropocene	Artificial	Human activity and human-made
Artificial	Artificial	Human activity and human-made
Complex	Assemblage	Comprises many interrelated and organised parts
Derelict land	Natural resource degradation	Degradation and contamination of natural resources
Development challenge	Sustainable development challenge	Rapid resource use consequences
Economic decline	Economic development and decline	Related to economic development
Economic development and opportunities	Economic development and decline	Related to economic decline and collapse
Inequality	Social justice	Social impacts and challenges
Governance	Governance	Authority, laws and regulations
Culture and heritage	Social impacts	Social challenges
Incompatibility	Natural resource degradation	Degradation and contamination of natural resources
Integrative rehabilitation and management	Integrative rehabilitation and management	
Legislation	Governance	Authority, laws and regulations
Multi-scalar	Assemblage	Comprises many interrelated and organised parts
Natural resource degradation	Natural resource use and degradation	Degradation and contamination of natural resources
Natural resources	Natural resource use and degradation	
Pollution	Natural resource use and degradation	Degradation and contamination of natural resources
Population decline	Population decline and collapse	
Social conflict	Social impacts	Social impacts and challenges
Social impact	Social impacts	Social impacts and challenges
Spatial	Spatial	
Sustainability challenge	Natural resources use and degradation	Rapid resource use consequences
Temporal	Temporal	
Transformation	Artificial/Complex	Human activity and human-made
Assemblage	Assemblage	Comprises many interrelated and organised parts

Appendix 34: Definitions of post-mining landscape characteristics identified from the literature

POST-MINING LANDSCAPE THEMES	DESCRIPTION	REFERENCES/DATA SOURCES
Anthropocene	This concept relates to the geological period whereby human activity, through mining-related activities have highly impacted natural conditions. Mining and agricultural activities are some of the main activities conducted by humans that cause a change in the landscape as the environmental conditions.	Svoboda et al. (2012), Digby 2008 (in Berger 2007)
Artificial	This concept relates to the change from natural conditions to conditions eminent from human interaction. In many regards, the post-mining landscape is a physical manifestation of human impact through mining activities. Post-mining landscapes are the physical manifestation of a human-produced landscape, distinct from the naturally occurring pre-mining conditions.	Harvest (2015), Marot and Harvest (2020), Svoboda et al. (2012), Hendrychova (2008), Lei et al. (2016), Misthos and Menegaki (2016), Genthe (2019), Kivinen et al. (2017), Kivinen et al. 2018, Bobbins and Trangos (2018), Berger (2002), Berger and Brown 2007 (in Berger, 2007), DEA/GTI 2018 30m SALNC
Assemblage (ontological basis)	When combined, this concept relates to many parts or characteristics that make the post-mining landscape whole. In the context of the post-mining landscape, the resultant landscape is characterised by the remnants of the natural landscape and the introduction of different niches and landforms (Mills et al. 2014).	Mills et al. (2014), Hermanus et al. (2015)
Complex	This concept relates to the many dynamic and related parts of post-mining landscapes. Hermanus (2015) suggests that post-mining landscapes' are connected and interrelated with surrounding natural and human communities.	Mya Piatek (2015), Audet et al. (2013), Hermanus et al. (2015)
Derelict land	This concept relates to certain parts of the landscape where economic activities have degraded and are now present as post-mining landscapes, characterised by waste and deterioration. These landscapes are often abandoned.	Balan (2020), Bini Berger (2006), Lei et al. (2016), CSIR (2019), SA Auditor General (2009), Funke et al. (2019), Limpitlaw and Briel (2014), Mills et al. (2014), Kivinen et al. (2017), Furlan (2019)Bobbins and Trangos (2018), Berger (2006), Berger and Brown 2008 (in Berger, 2007), DMR(2009)Abandoned mines, CGS (2012)Samindaba Abandoned mines, DEA/GTI (2020) SANLC 1990 30m, DEA/GTI (2020) SANLC 2020 30m
Development challenge	This concept refers to processes which impede further development and growth. Mining and mineral	Harfst (2015), Marot and Harfst (2021), Everingham et al (2018), Kivinen et al.

	extraction result in waste and permanent changes in a landscape. This is primarily due to the failure of mine planning to accommodate the extraction of minerals/energy resources in co-existence with established land uses, such as agriculture and ecological conservation. This often isolates some land areas as they are unsuitable for other uses. Post-mining landscapes are characterised by mounds of mine waste and degraded ecosystems, which are often unstable. As such, these post-mining landscapes are often isolated from development and planning efforts. In addition, post-mining landscapes are characterised by de-industrialisation and economic decline, which leads to sluggish development in these regions.	(2017), Hermanus et al. (2015), Bobbins and Trangos (2018)
Economic decline	In this instance, economic decline is related to the negative economic impacts of ceasing mining activities. The relationship between mining activities and economic development is also visible with de-industrialisation or the closure of mining activities, which often leads to the collapse of economic processes if an area has not established a separate economy. This leads to an increase in unemployment as well as limited economic opportunities and social vulnerability in post-mining landscapes.	Wende et al. (2017), Harfst (2015), Lorandelle and Haase (2012), Marot and Harfst (2021), Forget and Rossi (2020), Sklenicka and Kasparova (2008), Broemme et al. (2014), Berger (2006), Lei et al. (2016), CSIR (2019), Mthenjane (2019), Funke et al. (2019), Nortjie et al. (2019), Abad (2019), Limpitlaw and Briel (2014), Mills et al. (2014), Rich et al. (2019), Kivinen et al. (2017), Hermanus et al. (2015), Kabisch (2004), Kivinen et al. (2018), Digby 2008 (in Berger 2007),
Economic development	This concept relates to improving a region's economy and social well-being. Industrialisation and mining activities have contributed significantly to economic development in different contexts, creating job opportunities and qualifying regions for interaction in global markets.	Mya Piatek (2015), Harfst (2015), Kodir et al. (2017), Lei et al. (2016), CSIR (2019), Rich et al. (2019), Hermanus et al. (2015), Kivinen et al. (2018)
Inequality	This concept relates to the social impact of mining activities. The act of mining is characterised by disproportionate risk and cost. As such, the concept of inequality highlights the disproportionate benefits and risks.	Wende et al. (2017), Forget and Rossi (2020), Gabarron et al. (2019), Hermanus et al. (2015), Kivinen et al. (2018), Bobbins and Trangos (2018)
Governance	This concept relates to the activities of authoritative figures and decision-	Wende et al. (2017), Fagiewicz and Lowiki (2019), Harfst (2015), CSIR (2019)

	makers regarding mining and post-mining landscapes. Mining activities are highly political, and there can be a range of tensions between authoritative figures, local communities, and mining companies. Mineral commodities for most mining regions are very important in their development; mineral exploration is important to many governments. Moreover, it relates to how mining activities were initially governed by very lax legislation, and as such, post-mining landscapes have become the government's responsibility over time.	
Culture and heritage	This concept relates to the relationship between the post-mining landscape and the way of life of surrounding communities. Mining has tangible and intangible remnants. The post-mining landscapes are a physical, historical record of human interaction with the landscape.	Berger (2002), Esterhuysen et al 2018, Harfst (2015), Lorandelle and Haase (2012), Marot and Harfst (2021), Hook (2019), Popovic et al. (2015), Berger (2006), CSIR (2019), Abad (2019), Limpitlaw and Briel (2014), Mills et al. (2014), Furlan (2019), Digby 2008 (in Berger 2007)
Incompatibility	This concept relates to objects' differences that make it impossible for them to co-exist. In the context of post-mining landscapes, they result in alternative landscapes and niches, which overpower the naturally occurring characteristics of the landscape. Moreover, post-mining landscapes are visibly distinct from their surroundings due to the physical nature of extraction.	Mya Piatek (2015), Kuter (2013), Svoboda et al. (2012), Misthos et al. (2018), Sklenicka and Kasparova (2008), GDARD (2012), Abad (2019), Berger (2002), Berger and Brown 2008 (in Berger, 2007),
Integrative rehabilitation and management	This concept relates to the need for continuous monitoring, management and rehabilitation of post-mining landscapes. Rehabilitating these landscapes presents the opportunity to integrate these landscapes into development processes. This concept also relates to the malleability of post-mining landscapes.	Mya Piatek (2015), Wende et al. (2017), Harfst (2015), Lowry et al. (2018), Forget and Rossi (2020), Everingham et al (2018), Svoboda et al. (2012), Popovic et al. (2015), Bini (2017), Sklenicka and Kasparova (2008), Hendrychova (2008), Lei et al. (2016), GDARD (2009), SA Auditor General (2009), Mthenjane (2019), De Lange (2019), Abad (2019), Hancock et al. (2006), Audet et al. (2013), Fagiewicz and Lowiki (2019), Rich et al. (2019), Festin et al. (2019), Skousen and Zipper (2014), Hermanus et al. (2015), Furlan (2019), Kabisch (2004), Kivinen et al. 2018, Bobbins and Trangos (2018), Berger (2002)
Governance		Fagiewicz and Lowiki (2019), Holden's map of Johannesburg (1929), Gold mines and mineral rights of the greater Witwatersrand and Orange Free State (1949), Map of Pretoria and Heidelberg goldfields (1887), Witwatersrand (1890), Mendelssohn Jeppe

		Southern Goldfields (1896), Wylds new map of Witwatersrand Goldfields and district (1889), Fair et al. (1956), Fair et al. (1973), MPRDA (2006, NEMA (1998), DMR (2020) Draft closure strategy)
Multiscalar	This concept relates to how post-mining and mining impacts are experienced at different scales, locally and regionally. The waste on post-mining landscapes can directly affect a region by limiting space for development, pollution, etc. However, post-mining landscapes are also experienced regionally as toxic fumes are released into the atmosphere, contributing to climate change or waste leaching into the groundwater table.	Kivinen et al. (2017), Hendrychova (2008)
Natural resource degradation	This concept relates to the fact that mining activities are characterised by several activities which initiate land degradation, such as desertification, sedimentation, fracture development, environmental pollution, etc.	Mya Piatek (2015), Wende et al. (2017), Lowry et al. (2018), Lorandelle and Haase (2012), Kuter (2013), Balan (2020), Hook (2019), Toumbourou et a. (2020), Kodir et al. (2017), Dimitrakopoulous et al. (2016), Hendrychova (2008), Broemme et al. (2014), GDARD (2012), GDACE (2002), SA Auditor General (2009) , Statford et al. (2015), Mthenjane (2019), De Lange (2019), Magwedegwede et al. (2019), Funke et al. (2019), Genthe (2019), Abad (2019), Audet et al. (2013), Rich et al. (2019), Festin et al. (2019), Skousen and Zipper (2014), Fourie and Tibbett (2007), Kivinen et al. (2017)Kabisch (2004), Kivinen et al. (2018), Tredici 2008 (in Berger 2007), DEA/GTI (2018) 30m SALNC, Mya Piatek (2015), Harfst (2015), Kuter (2013), Marot and Harfst (2021), Forget and Rossi (2020), Svoboda et al. (2012), Kodir et al. (2017), Misthos et al. (2018), Lei et al. (2016), CSIR (2019), Misthos and Menegaki (2016), Genthe (2019), Limpitlaw and Briel (2014), Fagiewicz and Lowiki (2019), Skousen and Zipper (2014), Kivinen et al. (2017), Furlan (2019), Kivinen et al. (2018), Digby 2008 (in Berger 2007), Berger and Brown 2008 (in Berger, 2007)
Natural resource use	This concept relates to the naturally occurring resources that exist outside of the actions of humans. Natural resources are used at various levels of regional development. The extraction of naturally occurring mineral ores is a case in point.	Mya Piatek (2015), Forget and Rossi (2020), Popovic et al. (2015), Mborah et al. (2016), Lei et al. (2016), Statford et al. (2015), Krysztofik et al. (2020), Limpitlaw and Briel (2014), Fagiewicz and Lowiki (2019), Mills et al. (2014), Rich et al. (2019), Kivinen et al. (2017), Hermanus et al. (2015), Furlan (2019), Kivinen et al. 2018, Bobbins and Trangos(2018), Digby 2008 (in Berger 2007), Tredici 2008 (in Berger 2007), Berger and Brown 2008 (in Berger, 2007), DMR (2009,

		2011, 2014) Abandoned mines, CGS (2012) SAMINDABA, GTI (2014) 2.5m 2012 land cover (2014 release), DEA/GTI (2013/4) 30m 1990 SANLC, DEA/GTI (2013/4) 30m 2014 SANLC, DEA/GTI (2018) 30m SANLC, Holden's map of Johannesburg (1929), Gold mines and mineral rights of the greater Witwatersrand and Orange Free State (1949), Map of Pretoria and Heidelberg goldfields (1887), Fair et al. (1973), Morris and Rouse in Fair et al., Jeppe Southern Goldfields (1896)
Pollution	This concept relates to releasing particular wastes from active or post-mining and post-industrial activities into the environment (such as mine tailings) at a rate faster than they can be broken down to such an extent that normal environmental processes are adversely affected.	Harfst (2015), Marot and Harfst (2021), Balan (2020), Hook (2019), Svoboda et al. (2012), Toumbourou et al. (2020), Kodir et al. (2017), Gabarron et al. (2019), Popovic et al. (2015), Bini (2017), Hendrychova (2008), Berger (2006), Lei et al. (2016), CSIR (2019), GDACE 2002, De Lange (2019), Magwedegwede et al. (2019), Genthe (2019), Garland and John (2019), Hancock et al. (2006), Mills et al. (2014), Rich et al. (2019), Festin et al. (2019), Fourie and Tibbett (2007), Kivinen et al. (2017), Kabisch (2004), Bobbins and Trangos (2018), Digby 2008 (in Berger 2007), Berger and Brown 2008 (in Berger, 2007), GDARD (2009) Mine residue areas, GTI (2012) 2.5m land cover (2014 release, DEA/GTI (2020) 1990 30m SANLC, DEA/GTI (2013/14) 30m SALNC, GTI (2010) Land use (mapping rules), Holden's map of Johannesburg (1929), Gold mines and mineral rights of the greater Witwatersrand and Orange Free State (1949), Map of Pretoria and Heidelberg goldfields (1887), Jeppe Southern Goldfields (1896), Wylds new map of Witwatersrand Goldfields and district (1889), Fair et al (1956), Fair et al (1973), Morris and Rouse in Fair et al. (1973)
Population decline	This concept relates to the demographic impact of post-mining and post-industrialisation in mineral-rich regions. As mining and industrial activities cease in non-economically diverse regions, this leads to decreased economic opportunities; labour leaves for areas with more work opportunities.	Harfst (2015), Marot and Harfst (2021), Nortjie et al. (2019), Marias (2013), Speed (2014)
Social conflict	This concept relates to the struggles for power that arise between local communities and mining companies. The exploitation of underground assets is a controversial issue. While suitable for economic development, increasing research suggests that the social impact of mining activities is not enough. In post-mining	Kivinen et al. (2017), Hermanus et al. (2015), Kivinen et al. 2018, Bobbins and Trangos (2018)

	landscapes, surrounding communities face the permanent implications of mining, such as degraded land, economic and social vulnerability, etc.	
Social impact	This concept relates to the impact of mining on the surrounding population and communities. Mining activities bring employment,employment, asemployment, and some levels of development; however, their contributions to human well-being are uneven and often overwhelmed by the social and economic damage they inevitably inflict. The cessation of mining activities impacts local communities in several ways, e.g. increase in unemployment, lack of service delivery etc. In the context of post-mining, several other impacts are prevalent, such as public health-related issues from exposure to mine waste, etc.	Wende et al. (2017), Lorandelle and Haase (2012), Kuter (2013), Forget and Rossi (2020), Gabarron et al. (2019), Bini (2017), Mborah et al. (2016), Lei et al. (2016), CSIR (2019), GDACE (2002), SA Auditor General (2009), Mthenjane (2019), Nortjie et al. (2019), Hancock et al. (2006), Fagiewicz and Lowiki (2019), Rich et al. (2019), Kivinen et al. (2017), Hermanus et al. (2015), Kivinen et al. (2018), Bobbins and Trangos (2018), Digby 2008 (in Berger 2007)
Spatial	This concept relates to the location of mining and post-mining landscapes in a given space and the dimensions of space occupied by these activities.	Mya Piatek (2015), Harfst (2015), Lowry et al. (2018), Lorandelle and Haase (2012), Broemme et al. (2014), Fagiewicz and Lowiki (2019), Rich et al.(2019), Skousen and Zipper (2014), Furlan (2019), Kivinen et al. 2018, Bobbins and Trangos (2018), Digby 2008 (in Berger 2007), Berger and Brown 2008 (in Berger, 2007)
Sustainability challenge	This concept relates to the contradiction between mining activities, which are finite, and the biophysical environment. Mining activities generally entail extracting non-renewable mineral resources on the earth's surface, where the activities are abandoned as soon as they are unprofitable. As mineral resources are non-renewable, this contradicts the premise of sustainable development, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission for Environment and Development [WCED], 1987, p. 46).	Kuter (2013), Lei et al. (2016), Krysztofik et al. (2020), Hancock et al. (2006), Skousen and Zipper (2014), Kivinen et al. (2017), Digby 2008 (in Berger 2007)

Temporal	Mining activities can be long-term or short-term, depending on the abundance of resources and their profitability. However, the impact culminating from industrialisation and mining in mineral regions is long felt after the cessation of mining activities. For instance, the changes to the natural landscape are permanent, and mine waste may release waste into the surroundings long after the cessation of mining activity.	Kuter (2013), Limpitlaw and Briel (2014), Kivinen et al. (2017), Bobbins and Trangos (2018), Berger and Brown 2008 (in Berger, 2007)
Transformation	This concept refers to changing a landscape's natural structure and characteristics for extracting natural resources. Changes to the natural landscape and other natural systems are irreversible; they may be remedied, but the change to the original landscape is long-lasting.	Mya Piatek (2015), Harfst (2015), Kuter (2013), Marot and Harfst (2021), Forget and Rossi (2020), Svoboda et al. (2012), Kodir et al. (2017), Misthos et al. (2018), Lei et al. (2016), CSIR (2019), Misthos and Menegaki (2016), Genthe (2019), Limpitlaw and Briel (2014), Fagiewicz and Lowiki (2019), Skousen and Zipper (2014), Kivinen et al. (2017), Hermanus et al. (2015), Furlan (2019), Kivinen et al. 2018, Digby 2008 (in Berger 2007), Berger and Brown 2008 (in Berger, 2007)

Appendix 35*: Descriptions of urban landscapes from the literature*

URBAN LANDSCAPE CONCEPTS FROM LITERATURE		
Concepts	**Allocation of a new concept**	**Reason**
Artificial	Artificial	Human activity and human-made
Anthropocene	Artificial	Human activity and human-made
Assemblage	Assemblage	Comprises many interrelated and organised parts
Complex system	Assemblage	Comprises many interrelated and organised parts
Culture and Heritage	Social impacts	
Demarcation	Artificial	Human activity and human-made
Density	Density	
Derelict	Natural resource degradation	Degradation and contamination of natural resources
Development challenges	Natuarl resource use and degradation	Rapid resource use consequences
Economic development and opportunities	Economic development, opportunities and diversity	
Governance	Governance	
Inequality	Social impacts	Social impacts and challenges
Malleable	Complext/Artificial	
Mobility and mutual accessibility	Mobility and mutual accessibility	

Natural resource use	Natural resource use degradation	
Natural resource degradation	Natural resource use and degradation	Degradation and contamination of natural resources
Pollution	Natural resource use and degradation	Degradation and contamination of natural resources
Social conflict	Social impacts	Social impacts and challenges
Social impact	Social impacts	Social impacts and challenges
Spatial organisation	Assemblage	Comprises many interrelated and organised parts
Spatial	Spatial	
Sprawl	Artificial/waste	Rapid resource use consequences
Sustainability	Natural resource use and degradation	Degradation and contamination of natural resources
Temporal	Temporal	
Transformation	Artificial/Complex	Human activity and human-made

Appendix 36*: Definitions of themes and sources of urban landscape characteristics*

URBAN LANDSCAPES	DESCRIPTION	REFERENCES/DATA SOURCES
Anthropocene	This concept refers to the geological period whereby human activity has strongly influenced mpose changes the natural environment.	Zhang et al.(2019); Digby 2008 (in Berger 2008).
Artificial	This concept relates to the change from natural conditions to conditions eminent from human interaction. Both landscapes under investigation emanate from human interference.	Chylinska and Kolodziejczyk (2018); Wu et al. (2020); Lowell and Roberts (2010).
Inequality	Concept relates to the struggles for power that arise in urban settings. These struggles can manifest due to social injustices, environmental issues,diversity, political differences, disproportionate economic opportunities, costs and benefits, and inequitable distribution ofnatural resources.	Wende et al. (2017), Forget and Rossi (2020), Lei et al. (2016), Kivinen et al. (2017), Hermanus et al. (2015), Kivinen et al. (2017), Bobbins and Trangos (2018)
Social impact	Relates to the impact of urbanisation on the surrounding population and communities. Urbanisation is accompanied by a range of benefits, such as increased access to a vast array of services, for example, health, social services, food, education, and recreational services; which make life much more comfortable and raises living standards compared to rural areas. However, at the same time, urban areas may also negatively impact surrounding communities through societal challenges such as crime, air pollution, etc.	Wende et al. (2017), Lorandelle and Haase (2012), Kuter (2013), Forget and Rossi (2020), Gabarron et al. (2019), Bini (2017), Mborah et al. (2016), Lei et al. (2016), CSIR (2019), GDACE (2002), SA Auditor General (2009), Mthenjane (2019), Nortjie et al. (2019), Hancock et al. (2006), Fagiewicz and Lowiki (2019), Rich et al. (2019), Kivinen et al. (2017), Hermanus et al. (2015), Kivinen et al. (2017), Bobbins and Trangos (2018), Digby 2008 (in Berger 2008)

Density	Density in the context of urban forms relates to the concentration of large population and buildings. However, urban forms are also characterised by the concentration of economic and social activities. The concentration of economic activities is synonymous with economic opportunities and, thus, immigration and population growth in search of these opportunities. This leads to increased demand for land for human settlements, a shortage of which results in the overnight development of informal settlements, often close to core economic centres.The continued population growth strains service delivery and infrastructure in urban environments.	Xing and Meng (2020), Wu (2006), Sun et al. (2020), Goncalves et al. (2017), Brenner et al. (2011), McGranahan and Satterthwaite (2014), Wu et al. (2020), Lowell and Roberts (2010), Hough (1983), Deng (2020), Steurer and Bayr (2020), Fu et al. (2020), Storper and Scott (2016), StatsSA (1994/5), Sun et al. (2020), Wang and Yu (2012)
Derelict	Concept relates to certain parts of the landscape which have been degraded by economic that industrial activities, and used as waste disposal or sewage sites. These landscapes are often characterised by waste deterioration and abandonment.	Hough (1983), Qu et al. (2020)
Economic development and opportunities	Relates to improving a region's economy, governance capacity, and social well-being. Urban landscapes are often the product of industrial and mining activities, followed by structural transformation with continuous technological innovation and industrial upgrading, which increase labour productivity, and accompany infrastructure and institutions improvements reducing transaction costs. As such, these spaces become synonymous with opportunities for personal wealth accumulation.	Brenner (2009), Lombard and Rakodi (2016), Xing and Meng (2020), Hough (1983), Qadeer (1981), Rogerson et al. (2014), Deng (2020), Rickards et al. (2016), Qu et al. (2020), Sun et al. (2020), Wang and Gu (2020), Storper and Scott (2016), Bidandi and Williams (2020), Fu et al. (2020), Chylinska and Kolodziejczyk (2018), QuBaus et al. (2014)
Development challenges	This concept relates to the impact of urban land use processes and activities on future development prospects. Urbanisation requires using natural resources, which often results in a change in the natural functioning of ecosystems and natural systems, limiting the role that ecosystems can play in providing necessary ecosystem services. Moreover, many urban forms stem from industrial activities, where the resultant waste from these activities makes these spaces difficult to reintegrate into the urban frame.	GTI 2010 land use (2014 release), GTI 2012 2.5m land cover (2014 release), DEA/GTI 1990 30m SALNC, DEA/GTI 2013 14 30m SALNC, Rogerson et al. (2014)
Governance	This concept relates to the activities of authoritative figures and decision-makers as well as processes of social organisation in urban landscapes.	Brenner (2009), Shapiro (1959), Steurer and Bayr (2020), Lombard and Rakodi (2016), Bidandi and Williams (2020), Qadeer (1981)

Assemblage (ontological basis)	This concept relates to the heterogeneous nature of space Urban spaces consist of several parts, from economic and social structures to nature, to residential areas, infrastructure for service provision and technological innovations.	Maciocco (2008), Wang and Yu (2012), Gil et al. (2020), Wu et al. (2020), Lowell and Roberts (2010), Hough (1983), Shapiro (1959), Rogerson et al. (2014), Steurer and Bayr (2020), Rickards et al. (2016), , Lindholm (2012), StatsSA (1994/5), GTI 2010 land use (2014 release), GTI 2012 2.5m land cover (2014 release), DEA/GTI 1990 30m SALNC, DEA/GTI 2013 14 30m SALNC, Krier and Rowe (1979), Qadeer (1981), Seto et al. (2012), Qu et al. (2020)
Complex system	Concept relates to the dynamic nature of urban processes (ecological, economic, social and technical) and the interrelatedness of urban processes.	Sun et al. (2020), Bidandi and Williams (2020), Palermo (2008), Wang and Yu (2012), Qadeer (1981), Fu et al. (2020), Lindholm (2012), Qu et al. (2020)
Mobility and mutual accessibility	This relates to the availability of infrastructure to facilitate the movement of the population across the urban landscape. In urban landscapes, there are increasing transportation demands.	Xing and Meng (2020), Hough (1983), Qadeer (1981), Steurer and Bayr (2020), Rickards et al. (2016), Brenner et al. (2011), Rogerson et al. (2014)
Natural resource degradation	This concept relates to the deterioration of the natural resource assets involved with development the of urban landscapes. As urban landscapes develop, there is an increasing demand for various natural resources, such as land, water, etc. Moreover, the degradation of natural resources and various forms of development lead to a fragmentation of ecosystems.	Wang and Gu (2020), Baus et al. (2014), Brenner et al. (2011), Wu et al. (2020), Hough (1983), Qadeer (1981), Rogerson et al. (2014), Steurer and Bayr (2020), Fu et al. (2020), Storper and Scott (2016), Lindholm (2012), Qu et al. (2020), Sun et al. (2020), Hough (1983)
Pollution	. Urban forms employ a range of activities that result in insurmountable pollution, from industry and manufacturing to agricultural practices and by-products of households. This concept relates to the release of particular wastes from urban processes into the environment at a rate faster than they can be broken down to such an extent that normal environmental processes are adversely affected.	Pan et al. (2012), Hough (1983), Deng (2020), Steurer and Bayr (2020)
Spatial	This concept relates to the location of urban landscapes in a given space and the dimensions of space occupied by these activities.	Xing and Meng (2020), Baus et al. (2014), Maciocco (2008), Fu et al. (2020), Bidandi and Williams (2020), Wang and Yu (2012), Lowell and Roberts (2010), Qu et al. (2020)
Malleable	This concept relates to the changes experienced by natural environments due to urban activities and the malleable nature of urban landscapes.	Chylinska and Kolodziejczyk (2018),Wang and Gu (2020), Bidandi and Williams (2020), Palermo (2008), Wu et al. (2020), Lowell and Roberts (2010), Lindholm (2012), Brenner (2009), Wu et al. (2020)
Spatial organisation	To make urban landscapes more meaningful and efficient, the urban landscape is characterised by various spatial patterns and arrangements. In the context of urban landscapes in South Africa, the spatial patterns of urban	Xing and Meng (2020), Wu et al. (2020), Maciocco (2008), Zhang et al.(2019), Gil et al. (2020), McGranahan and Satterthwaite (2014), Hough (1983), Shapiro (1959), Rogerson et al. (2014), Steurer and Bayr (2020), Seto et al. (2012), Lindholm (2012),

	landscapes have inherited the exclusionary spatial patterns of the apartheid regime.	Myers (2018), GTI (2010) land use (2014 release), GTI (2012) 2.5m land cover (2014 release), DEA/GTI (1990) 30m SANLC, DEA/GTI (2013/14) 30m SALNC
Temporal	This concept relates to the time element of urban processes with the landscape. Urban processes are dynamic and constantly evolving.	Wang and Yu (2012), Deng (2020),
Transformation	This concept refers to changing a landscape's natural structure and characteristics due to urban processes. Changes to the natural landscape and other natural systems are irreversible; they may be remedied, but the change to the original landscape is long-lasting.	Mya Piatek (2015), Harfst (2015), Kuter (2013), Marot and Harfst (2021), Forget and Rossi (2020), Svoboda et al. (2012), Kodir et al. (2017), Misthos et al. (2018), Lei et al. (2016), CSIR (2019), Misthos and Menegaki (2016), Genthe (2019), Limpitlaw and Briel (2014), Fagiewicz and Lowiki (2019), Skousen and Zipper (2014), Kivinen et al. (2017), Hermanus et al. (2015), Furlan (2019), Kivinen et al. 2018, Digby 2008 (in Berger 2008), Berger and Brown 2008 (in Berger 2018)

Appendix 37*: Collapsed Google Forms survey results of post-mining and urban landscape characteristics from local experts*

KEY CHARACTERISTICS OF POST-MINING LANDSCAPES	KEY CHARACTERISTICS OF URBAN LANDSCAPES
• point==*spatial* • polygon=*spatial* • disturbed landscape=*natural resource degradation* • pollution=*natural resource degradation* • road infrastructure=*artificial/mobility and mutual accessibility* • rail infrastructure=*artificial/mobility and mutual accessibility* • crime=*economic decline and collapse/social justice* • residential areas=*economic development and opportunities/social justice* • agricultural small holdings=*economic development and opportunities* • hit and run economy=*economic decline and collapse* • unsustainable=*sustainable development challenge* • negative impacts=*natural resource degradation*	• points=*spatial* • polygons=*spatial* • mine waste=*natural resource degradation/sustainable urban development challenge* • mine residue areas=*natural resource degradation/sustainable urban development challenge* • gold extraction=*natural resource use* • landscape fragmentation=*natural resource degradation/sustainable urban development challenge* • urban development=*artificial/economic development and opportunities* • rural development=*artificial/social justice/economic development and opportunities* • urban land cover=*artificial/economic development and opportunities* • natural land cover=*natural resource use*

• fragmented populations=*sustainable urban development challenge/economic decline and collapse* • mine dumps=*natural resource degradation* • acid mine drainage=*natural resource degradation* • desolate communities=*economic decline and collapse/social justice* • devastated communities=*economic decline and collapse/social justice* • poverty=*economic decline and collapse/social justice* • *mine land licenses=social justice/governance* • unrehabilitated/unreclaimed mining=*sustainable development challenge* • open pit mine=*natural resource use* • underlain mining ground=*natural resource use* • subsidence=*natural resource degradation* • varying income levels=*social justice* • ownership issues=*social justice/governance* • derelict infrastructure=*sustainable development challenge/economic decline and collapse* • ruins =*sustainable development challenge* • water provision=*artificial* • electricity provision=*artificial* • extent of mining areas and activity=*spatial/temporary* • informal dwellings=*social justice* • mine waste=*natural resource degradation* • extraction =*natural resource use* • soil contamination=*natural resource degradation* • groundwater contamination=*natural resource degradation* • land use change=*natural resource use/spatial/temporal/artificial/assemblage*	• degraded natural environment=*natural resource degradation/sustainable urban development challenge* • built environment=*artificial/economic development and opportunities* • telecommunication lines=*artificial /mobility and mutual accessibility/economic development and opportunities* • electricity lines=*artificial/economic development and opportunities* • high population density=*density/social justice* • water pipes=*artificial/ basic services/economic development and opportunities* • sewerage pipes=*artificial/ basic services/economic development and opportunities* • residential densities=*artificial/density* • road infrastructure= *artificial/mobility and mutual accessibility/economic development and opportunities* • economic centre=*economic development and opportunities/social justice* • industrial waste=*natural resource degradation/sustainable urban development challenge* • inclusive economy=*economic development and opportunities/social justice/assemblage* • dying industries=*economic decline and collapse/social justice* • urban blight=*economic decline and collapse/social justice/natural resource degradation/sustainable urban development challenge* • informal settlements=*economic decline and collapse/social justice* • investment=*economic development and opportunities* • marginalised communities=*economic decline and collapse/social justice* • inequality=*economic decline and collapse/social justice*

• grime=*economic decline and collapse/social justice* • derelict spaces=*sustainable development challenge* • sinkholes=*natural resource degradation/ sustainable development challenges* • abandoned shafts=*sustainable development challenge* • sparse vegetation=*natural resource degradation* • boosts economy=*economic development and opportunities/assemblage* • social consequences=*social conflict* • environmental consequences=*natural resource degradation/sustainable development challenge* • economic consequences=*economic decline and collapse/social justice* • degraded=*natural resource degradation/sustainable development challenge* • contamination=*natural resource degradation/sustainable development challenges* • wastelands=*natural resource degradation/sustainable development challenge* • tailing dams=*natural resource degradation/sustainable development challenge* • slums=*natural resource degradation/sustainable development challenges*	• politics=*governance* • poverty=*economic decline and collapse/social justice* • agglomeration=*economic development and opportunities/assemblage* • settlements=*economic development and opportunities/social justice* • diverse landuse=*assemblage/malleable* • tertiary economic activity=*economic development and opportunities/assemblage* • social mixing=*economic development and opportunities/social justice /density* • racial mixing=*social justice*/density • industry=*economic development and opportunities/assemblage* • mining=*economic development and opportunities* • agriculture=*natural resource use/economic development and opportunities/assemblage* • communal land=*governance/social justice* • transport networks=*artificial /mobility and mutual accessibility/economic development and opportunities* • diverse land use=*economic development and opportunities/assemblage/malleable* • diverse cultures=*assemblage* • infrastructure=*economic development and opportunities/assemblage* • boundaries=*spatial/governance*