Developing a National Mine Closure Risk and Opportunities Atlas in GIS for South Africa

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Master of Philosophy

Sustainable Mineral Resource Development

2023

Faculty of Engineering and the Built Environment

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minerals to metals

WATER RESEARCH COMMISSION

NRF National Research Foundation

Abstract

Mining is entrenched in South Africa's history and has played a crucial role in the country's socio-economic and geopolitical development. There are currently 230 operating large-scale mines owned by 104 mining companies and hosted by 360 urban and rural communities across South Africa, comprising of approximately 6 million people – many of whom depend on mining for employment (Cole, 2024). While the impact of mine closure is well-known (Besa, et al., 2019), quantifying the extent of its impacts is not straightforward. This is particularly relevant in South Africa, where impacts may be localised due to variations in mining host community size, location, physical environmental characteristics, local infrastructure, business activity and current local economic well-being. Furthermore, determining opportunities for the post-closure phase also depends on local scenarios. South African legislation recognises the need to plan for sustainable mine closure (Mineral and Petroleum Resources Development Act, No. 28 of 2002, 2004), however there is limited tools and / or standard guidance to support this. This dissertation forms one aspect of a three-year research project funded by the Water Research Commission (WRC) aimed at producing mine closure risk ratings for all large-scale mines and a post-closure land use opportunity framework to inform and support mine closure planning. A South African Mine Closure Risk and Opportunities Atlas ('the Atlas'), a novel analytical tool, has been developed on the basis of extensive collection of quantitative data and the visualisation thereof by means of developing a publicly available GIS tool using ArcGIS and QGIS software, with inputs from various stakeholders and industry mine closure experts following a comprehensive literature review that includes a review of existing GIS tools and methods to design such tools. It partly serves to integrate the data collected for the WRC project. Expert input informed the iterative development of the Atlas through presentations and semi-structured interviews, which guided the layout of the Atlas and the data it contains. The final result is a publicly available online and interactive Atlas which contains a comprehensive set of data that can be visualised in accordance with the identified requirements of stakeholders and experts in the field of mine closure and post-closure development planning. Through its integration of a considerable quantum of data and analytical tools, the Atlas is presented as an important tool that allows for analyses at regional scales (a key principle the South African Draft Mine Closure Strategy (2021)) as well as more local / granular scales which is useful for the identification of potential localised impacts of mine closure and opportunities for post-closure land use development. The Atlas aids mine closure and post-closure land use development planning by providing all affected stakeholders with a single platform in which they can access and interpret information that can influence decision-making processes. Iterative development of the Atlas provided for a number of issues that can be addressed in further development of the Atlas, including continuous updating of the data contained in the Atlas and the inclusion of mining host community members in development processes.

Statement of Originality

I know the meaning of plagiarism and declare that all the work in the document, save for that which is properly acknowledged, is my own. This thesis/dissertation has been submitted to the Turnitin module (or equivalent similarity and originality checking software) and I confirm that my supervisor has seen my report and any concerns revealed by such have been resolved with my supervisor.

Signed by candidate

Murad Esau

Acknowledgements

آمنتُ بالله وملائكته
وكتبه ورسوله واليوم الآخر
والقدر خيره وشره من الله
والبأس بعد الموت
لا إله إلا الله

"I believe in Allah

And His Angels and His Books and His Messengers and the Hereafter

And the decree good and bad from Allah

There is no God but Allah."

I extend my heartfelt gratitude to my supervisor, Dr. Megan Cole, whose trust, belief and guidance empowered me to push the boundaries of this project. Without her unwavering support, I would not have had the courage to undertake the challenges that defined my Master's journey.

To my esteemed colleagues at SRK Consulting (South Africa) (Pty) Ltd, your patience during the pursuit of my Master;'s degree and your constant words of encouragement and wisdom throughout 2023 have been invaluable. Your support made this journey even more rewarding.

Mom (Sumaya Davids Esau) and Dad (Rezah Esau), shukran for being the pillars of support throughout my entire academic career. Your belief in me fuelled my aspirations. All I ever wanted was to make you proud. This accomplishment is as much yours as it is mine.

A special thank you to the brother at Varsity Fast Foods who brightened my lunch breaks with a zinger wrap with avocado. Your kindness made my days lighter, and to the uncle at Coffee to Go, Sheikh, your gestures were a source of joy on countless occasions.

I express my deepest gratitude to the National Research Foundation of South Africa (NRF) for generously funding my postgraduate academic journey over the past three years. The NRF's financial support has been instrumental in making this achievement possible.

I am indebted to the Water Research Commission for providing the opportunity to embark on such an ambitious project. My sincere appreciation goes to the project Reference Group for their valuable insights, which enriched the quality of my work.

A heartfelt thank you to all the participants of this project. Your contribution has been pivotal, and the achievement would not have been possible without your collaboration.

Lastly, my appreciation goes to everyone who supported and encouraged me throughout the pursuit of my Master's degree, On the darkest of days, there was always someone standing in my corner to offer comfort. It truly takes a village to raise a child.

ٱلْحَمْدُ لِلَّهِ

Contents

Appendices

List of Figures

List of Tables

Abbreviations and Acronyms

AI	Artificial Intelligence

AMD	Acid Mine Drainage
BGIS	Biodiversity Geographic Information Systems
CT	Creative Technology
DFFE	South African Department of Forestry, Fisheries and the Environment
DMRE	Department of Mineral Resources and Energy
DNI	Direct Normal Irradiation
EIA	Environmental Impact Assessment
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
ICMM	International Council on Mining and Metals
KML	Keyhole Markup Language
LM	Local Municipality
LoM	Life of Mine
MCDM	Multi-criteria Decision Making
MPRDA	Mineral and Petroleum Resource Development Act 28 of 2002
NGO	Non-governmental Organisation
NPAES	National Protected Areas Expansion Strategy
NQF	National Qualifications Framework
NTC	National Technical Certificate
PGM	Platinum Group Metals
SANBI	South African National Biodiversity Institute
SDG	Sustainable Development Goal
SLP	Social and Labour Plan
StatsSA	Statistics South Africa
SWSA	Strategic Water Source Area
TSF	Tailing Storage Facility
UBA	Umwelt Bundsmant
UX	User Experience
WRC	Water Research Commission

CHAPTER 1

1. Introduction

1.1. Background

Contemporary South Africa is entrenched with a rich history of mining activity that has been established as a major contributor to the country's socio-economic and geo-political development. The discovery of mineral deposits prompted the development of the mining sector in the 1800s (Cole & Broadhurst, 2020). Copper, tin and iron ore deposits were first discovered and mined by the indigenous people of Limpopo and Namaqualand before European colonists arrived and developed them into large-scale mines (Cairncross, 2004). Diamonds were discovered in the 1860s in Griqualand West (now Kimberly) in the Northern Cape province which spurred the opening of diamond mines across the North of the country under the British Cape Colony (Cole & Broadhurst, 2020). The gold rush started in Barberton in the early 1880s before the Witwatersrand Basin (the world's biggest goldfield) was discovered in the former Transvaal region (Northeast of South Africa) and reshaped the Boer Republic's declining economy (Meredith, 2008). Gold mining was focussed in the central, east, west and far West Rand regions, with deposits later discovered in the Free State in the 1940s. Coal was first discovered in the Eastern Cape province in 1864 and later near Indwe. The coal industry boomed as a result of growing demand, with coal mining being further developed in Northern Natal and in the west, central and eastern Transvaal regions. In the Northern Transvaal and the Northern Cape, iron ore and manganese were mined from the late 1920s, supplying the former state-owned Iron and Steel Corporation of South Africa (Iscor) (Cole & Broadhurst, 2020). Lastly, Platinum Group Metals (PGMs) and chromium were discovered in the mid-1920s in the Bushveld Complex, which rapidly expanded since the discovery of mineral deposits in the region (Cole & Broadhurst, 2021).

Although mining's contribution to the country's Gross Domestic Product (GDP) has declined since it peaked in the 1980s, it remains a vital contributor to South Africa's economy (Cole & Broadhurst, 2020). In 2021, the industry contributed R480.9 billion (8.7%) to the GDP, employed 458 954 people, and contributed R78.1 billion in taxes (Minerals Council South Africa, 2022). Mining companies also make valuable contributions to the development of mining communities in South Africa, often developing critical aspects such as infrastructure, schools, and health care facilities. (Cole & Broadhurst, 2020).

The demand for minerals fluctuates according to external pressures (Toledano, et al., 2020). With the world moving towards a 'Just Transition', South Africa is vulnerable to mine closure risks. The demand for coal is decreasing and minerals such as manganese (of which 80% of the world's deposits are found in South Africa) are increasing as the world moves away from the burning of fossil fuels to the development of renewable technologies for energy production (ActionAid Netherlands, 2021). The closure of mines in South Africa is imminent (Cole, et al., 2023) . Closure planning must not only take place for mines with a vision of closure, but also for new mines – planning for mine closure at the inception of a mine is standard good practice (International Council on Mining & Metlals, 2019).

Furthermore, land that will no longer be used for mining provides opportunities for development that satisfies local, regional and/or national requirements for economies without mining activity and aiding the development of other industries (such as the energy sector).

As of 2020, approximately 36 South African communities have been impacted by mine closure and/or downscaling since 1852 (Cole & Broadhurst, 2020). While the impact of mine closure is well-known (Besa, et al., 2019), quantifying the extent of its impacts is not straightforward. This is particularly relevant in South Africa, where impacts may be localised due to variations in host community size, location, physical environmental characteristics, local infrastructure, business activity and current local economic well-being. As a result, mines across South Africa have unique risks associated with their closure. Impacts may also be wider spread, with regional economies at risk of mine closure due to overreliance on regional mining economies that are centred on one type of mineral. Furthermore, determining opportunities for the post-closure phase also depends on local scenarios. South African legislation recognises the need to plan for sustainable mine closure (Mineral and Petroleum Resources Development Act, No. 28 of 2002, 2004). However, determining environmental and social vulnerability to individual mine closure and post-closure opportunities may prove challenging.

While there is a vast array of data and information available in the public domain, many stakeholders affected by mine closure may not be aware of it. Additionally, the scattered nature of the information and data may prove challenging in the face of carrying out complex analyses. The Atlas is presented as a single platform that integrates diverse datasets while making them easily accessible to the public. It is a central node that connects segregated information sources (Esau, et al., 2023).

The Atlas will make the following operations possible (Esau, et al., 2023):

- Make information about mines and mining communities and their associated risks and opportunities publicly available;
- Provide a visual comparison of the likelihood of mine closure, socio-economic risk and environmental risks for all operating mines; and
- Provide an analytical tool to assess mine closure risks and post-closure land use opportunities by making relevant spatial datasets accessible and user-friendly.

1.2. Problem Statement

While there is a large amount of data and information available in the public domain that may inform mine closure planning, there is currently no platform which integrates all this information, aids the quantification of mine closure risks and/or the identification of post-closure land use opportunities. Failing to consider all relevant information in a cohesive manner may result in improper mine closure leading to negative socio-economic and environmental impacts. Geographic Information Systems (GIS) is a suitable platform to organise and integrate information and facilitate data visualisation processes to aid mine closure and post-closure planning. An interactive online Atlas[1] developed in GIS may facilitate this process.

[1] A collection of maps (National Geographic, 2023).

1.3. Project Scope

This study entails four main tasks summarised in Table 1 below. Each task corresponds with a respective approach taken to achieve them.

Table 1: Main tasks and corresponding approach to completing them.

Task	Approach
Quantitative data collection	• Collect spatial and discrete data associated with risks of mine closure and post-closure land use opportunities in South Africa from various sources; • Integrate data from Water Resource Commission (WRC) (to whom this research is attached to as part of a broader research project) on mine closure risk quantification and land use opportunity frameworks; and • Compile the data into usable formats using GIS and Microsoft Excel.
Data visualisation	• Communicate data using visualisation techniques and formatting facilitated by GIS.
GIS tool development	• Use the data to develop a GIS tool which displays the data visuals and enables users to perform various operations (such as distance measurement)
Presentation and testing	• Present the Atlas to stakeholders and practitioners from various segments of the mining industry to gain an understanding of the Atlas's usability in real-world scenarios; and • Engage in user testing by industry professionals to obtain feedback on data inclusion and usability

The aspiration of this project is to develop a GIS tool to aid decision-making processes in mine closure planning and post-closure land use development. The GIS tool is intended to be used by all stakeholders to ensure transparency in the decision-making process. Using the same tool (and examining the same data) will improve partnerships and trust between stakeholders. While mapping mine closure risks and post-closure land use opportunities for all mines in South Africa is already an ambitious undertaking, it may be difficult to assess the finer details of every region. For example, it may be impractical to assess the social dynamics of all 360 mining host communities in South Africa. In addition, the development of a GIS tool such as this will require maintenance over time. This is due to data being updated in the different source databases used. As a result, the scope of this project only allows for a snapshot of mine closure risks and post-closure land use opportunities to be identified using the Atlas, which may have the capacity to be updated beyond the timeline of this project.

1.4. Research Questions

In line with the objectives stated above, this research seeks to answer the following questions:

- What data should be included in the Atlas to aid the assessment if mine closure risks and opportunities for post-closure land use development in South Africa?
- How can the Atlas be designed to best support decision making and communication of information associated with mine closure planning?

- How can the Atlas conform with current legislation and mine closure planning practices?
- How will the Atlas be made to be accessible and comprehensible to all the stakeholders?

1.5. Research Approach

A mixed methods approach was utilised for this study. Quantitative data was collected from various online and organisational sources for the development of the Atlas database. Qualitative data was collected to optimise the functionality of the Atlas as well as gain expert input on the type of data to be included in the Atlas.

Conceptualisation of the Atlas builds on the work of Cole & Broadhurst (2020; 2021) who mapped and classified all mining host communities in South Africa and their progress towards the Sustainable Development Goals (SDG). The development process was guided by Mader & Eggnik's (2014) concept of Creative Technologies (CT). Basic specifications for the Atlas were determined firstly, by the authors, and secondly, by experts in the mining industry. After presentation and testing of the Atlas through various stages of development by experts and stakeholders, their feedback was provided realisation of the Atlas's overall functionality and capability. A final version of the Atlas was evaluated by experts by the WRC research team's reference group.

This study runs in parallel with the WRC-funded research project on Developing National Mine Closure Risk Ratings and Opportunity Framework for South Africa. The bulk of this research took place during Phase 2 (Data Collection and Analysis) of the WRC's research project schedule. The Atlas was used as a tool to assess four case study areas that were part of the WRC's research project. Three of these case study areas were assessed for the purpose of this study (see Sections 3.4 and 4.3).

1.6. Structure of this Dissertation

This dissertation is presented in six chapters, as outlined below and summarised by Figure 1:

- CHAPTER 1 (this Chapter) introduces the study, providing a background; the subsequent problem statement; the overarching aim; and scope of the study. Key Research questions the and research approach is also presented;
- CHAPTER 2 provides an extensive review and analysis of published literature relevant to mine closure; data visualisation; User Experience design; GIS; its context in mine closure in South Africa; and existing GIS tools;
- CHAPTER 3 describes the methodology used in this study. Quantitative and qualitative data collection methods are described and explained;
- CHAPTER 4 presents the results of this study, including the final Atlas, outcomes of data collection and maps of case study areas produced using the Atlas;
- CHAPTER 5 presents the discussion of the process of developing the Atlas; its implications for policy; key outcomes of feedback gained from industry experts; and case study areas; and
- CHAPTER 6 synthesises the findings of this study. Conclusions are drawn and recommendations for further research are also presented.

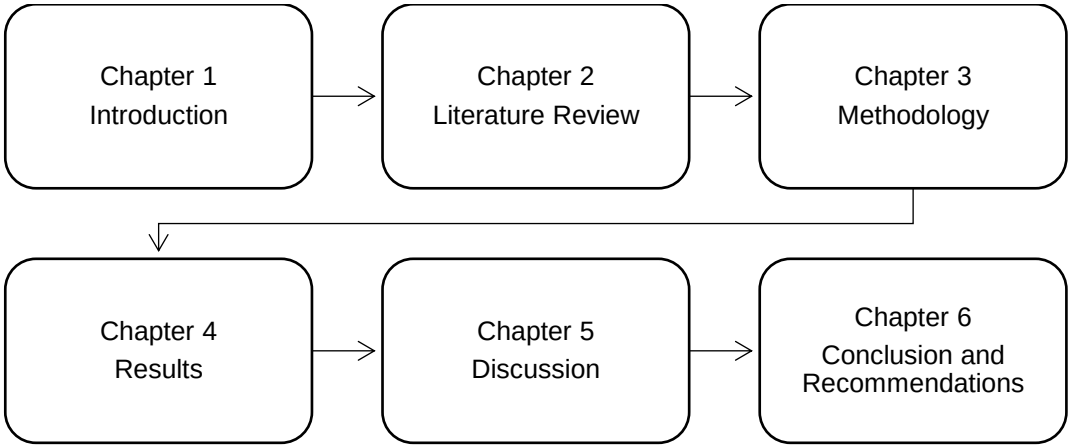

Figure 1: Graphic illustration of the dissertation structure

CHAPTER 2

2. Literature Review

The use and development of GIS started generating great amounts of interest in the late 1980s and early 1990s (Maguire, 1991). The versatility of GIS enabled the integration of existing ideas from a variety of disciplines (such as agriculture, economics, and mathematics) into a single place (Maguire, 1991). Essentially, GIS acts as a place to bank and store information from multiple sources (Andreev, 2021). There is no surprise that the capabilities of GIS are exploited by the mining industry. According to Werner *et al.* (2019), GIS is conventionally used for mineral exploration, Environmental Impact Assessment (EIA), and ongoing mine management in the mining industry.

Literature pertaining to the use of GIS during the closure stage of the mining life cycle primarily focuses on the identification of rehabilitation projects rather than the identification of risks and opportunities of mine closure. Esri, a well-established organisation that deals with the development of various GIS products, states that GIS tools can be used for processing closures and planning reclamation activities (Esri, 2018). However, the development of a GIS tool to identify risks and opportunities of mine closure is a relatively novel concept.

The dominant paradigm of the impacts of mine closure focuses on physical environmental impacts (Besa, et al., 2019; McCullough, 2016). However, the complex nature of mine closure means that it also has socio-economic impacts (McCullough, 2016). The International Council for Minerals and Metals (ICMM) (2019) states that best practice mine closure planning requires continuous engagement with mining host communities to avoid the associated impacts; starts at the earliest possible stage (preferably at the inception of a mining project); and is an iterative process. GIS has the capability to aid these processes through its ability to visually integrate existing knowledge bases in order to aid effective decision-making throughout the life cycle of a mine for mine closure based on existing data (Andreev, 2021).

Other forms of data visualisation for communication and its use for risk identification have been extensively studied (Stretcher, et al., 1999; McInerny, et al., 2014; Lipkus & Hollands, 1999; Johnson & Johnson, 2001; Spiegelhalter, et al., 2011; Ancker, et al., 2006). The principles emphasised in ‘conventional’ data visualisation and communication may apply to the design and development of geospatial data visualisations and communication, such as an interactive map tool/atlas that is developed using GIS.

The purpose of this literature review is to analyse literature pertaining to GIS and data communication to explore how GIS can be used as a tool to communicate the risks and opportunities of mine closure in South Africa. Approaches for developing effective visual communication and GIS development will be discussed, as well as its relevance to mine closure in South Africa. The literature review is organized in the following order: first, a brief background of mine closure is presented to give context to the discussion. Data visualisation techniques and principles will then be discussed and analysed to evaluate

their effectiveness. Then, approaches to the development of GIS produced outputs will be discussed, with a focus on identifying a suitable methodology for developing a GIS tool for the context of mine closure risks and post-closure land use opportunity assessment. Lastly, the topics discussed will be applied to the context of mine closure in South Africa. This literature review fosters the development of the Atlas by providing an understanding of which practices are most suitable for the development of the Atlas in the context of assessing mine closure risks and post-closure land use opportunities in the South African context.

2.1. Mine Closure

2.1.1. Planned vs. Unplanned Closure

Mine closure is either a foreseeable expectation that is planned for according to a predicted timeline; or is an event that can occur abruptly for various reasons (McDonald, et al., 2012). The 'Big Hole' in Kimberly, South Africa, is an example of a mine closure that was planned for by the De Beers Group. At the end of the Kimberly Diamond Mine's life, it was filled to reduce its depth and the area was developed into a tourist attraction (Van der Merwe & Rogerson, 2013). Infrastructure and historical buildings around the mine were turned into a museum and a nearby town was refurbished to resemble historical architecture, making the area reminiscent of a townscape (Van der Merwe & Rogerson, 2013). A viewing platform was also constructed over the actual mine (hole) to enhance tourism (Van der Merwe & Rogerson, 2013).

Contrasting to the interesting work done with the closure of the Kimberly Diamond Mine is the sudden closure of the Ravensthorpe nickel mine in Western Australia. The Ravensthorpe mine underwent sudden closure as a result of changes in global demand and supply of nickel (McDonald, et al., 2012). While there were negative impacts on mine employees who lost their jobs, McDonald *et al.* (2012) explore the broader impact that the sudden closure had on the communities which depended on the mine. In their study, McDonald *et al*. (2012) states that areas surrounding a particular mine may contain more than a single community – often home to multiple subgroupings within the geographical area. The result is that the consequences of mine closure extend beyond mine employees to those living in the multiple mining communities who indirectly depend on the mine for their own livelihoods (McDonald, et al., 2012).

2.1.2. Impacts of Mine Closure

According to Besa *et al*. (2019), mine closure planning typically has a dominant focus on physical environmental aspects. This includes impacts such as land disturbances, soil degradation, dust emissions, and water contamination (Smith & Underwood, 2000; McCullough, 2016). However, it is critical to perceive mine closure with respect to the complexity of the systems in which it operates. This includes understanding the link between environmental impacts and socio-economic impacts. Socio-economic impacts of mine closure include aging populations, an increase in illegal mining, outflow of capital from a region, and a decline in standard of living (Petrov, 2010; Hilson, 2010). An environmental impact may cause or exacerbate a socio-economic impact and vice versa. This is characteristic of complex systems (Folke, et al., 2016). For example, soil degradation may hinder the possibility of newly

unemployed people from building a livelihood through agricultural practice. Thus, planning for mine closure is crucial to avoid negative impacts which could lead to a breakdown of the complex socio-economic and environmental system.

2.1.3. Mine Closure Planning

According to the ICMM (2019), best practice mine closure planning includes the development and implementation of a mine closure plan at the earliest stage possible. Ideally, this would be before any physical mining of minerals or alterations of physical landscape takes place – possibly during the prospecting phase. Furthermore, it is important to note that a mine closure plan requires linear implementation and is an iterative process (International Council on Mining & Metlals, 2019). In other words, a mine closure plan is implemented throughout the life cycle of a mine and requires constant reflection on measures that are put in place (International Council on Mining & Metlals, 2019). A crucial element of this is continuous community engagement (International Council on Mining & Metlals, 2019). This is required to understand the opinions and concerns of affected stakeholders and may greatly improve the success of a mine closure plan (International Council on Mining & Metlals, 2019). As McDonald *et al*. (2012) imply, it may be up to local mining affected communities to ultimately decide what happens to land after mine closure. Even though quantitative data may suggest that a particular type of development is the best suited alternative for a post-closure development, local communities may reject the development due to various reasons (e.g., cultural beliefs) (McDonald, et al., 2012). Decision-making processes for post-closure land use requires stakeholders, including local communities, and existing knowledge bases to be considered to effectively develop a region beyond the life of a mine so that economic stability and social cohesion is maintained (Starke, 2002).

2.1.4. Failed Mine Closure Planning

Main risks associated with mine closure are environmental, safety and community risks; final land use; and legal, financial and technical risks (Laurence, 2006). It is imperative that the risks of mine closure are identified as it guides mining companies to direct resources to individual sites which require more, or less, robust mine closure plans to avoid the associated impacts – this is particularly relevant for larger mining companies (Laurence, 2006). This may also enable plans for post-closure opportunities to develop as resources become available. This includes, among others, implementation of economic diversification strategies to sustain the economic longevity of the region; renewable energy plants on land previously used for mining activity (such as the development of solar and/or wind energy facilities on Tailing Storage Facilities [TSF]); and/or tourism and recreation sites to stimulate local economies (Marais & Nel, 2016; Edwards & Maritz, 2019).

The risks of failing to implement and execute a mine closure plan is not limited to mining host communities. Mining companies and governments are also at risk (The World Bank and International Finance Corporation, 2002). While communities may face serious distress due to the potential economic and social collapse, mining companies incur safety, environmental and social risk liabilities if mine closure planning fails (The World Bank and International Finance Corporation, 2002). Failure of governments to adequately implement suitable frameworks may result in environmental liabilities to

them, as well as expenses associated with rectifying environmental damages caused (The World Bank and International Finance Corporation, 2002). It is ultimately in the hands of mining companies to develop and implement effective mine closure plans that facilitate benefits or catalyse disaster if they do not. It is the responsibility of government to regulate these processes to ensure effective mine closure that mitigates negative impacts.

2.2. Data Visualisation and Communication: Key Principles and Considerations

There are many stakeholders from various different backgrounds involved in the process of mine closure planning (International Council on Mining & Metlals, 2019). Consequently, individual stakeholders may have different levels of education and ability to comprehend data pertaining to mine closure risks and opportunities. The broad spectrum of stakeholders may range from local community members, who do not have access to formal education, to Chief Executive Officers of mining companies who possess several tertiary level qualifications. According to McInerny *et al*. (2014), even if knowledge is made easily accessible to all stakeholders, scientific knowledge requires expertise to be understood. Not all stakeholders may have this type of expertise (McInerny, et al., 2014). According to Lipkus & Hollands (1999), the success of efforts to communicate risks requires an understanding of the intended audience's characteristics, with the authors alluding to the potential of visually communicated data to facilitate comprehension of risks, particularly for the so-called 'lay pubic' (i.e., people who may not have the necessary expertise to comprehend numerical data). Ancker *et al*. (2006), who build on the work of Lipkus & Hollands (1999), demonstrate the difficulty in presenting information numerically to the lay public, who may find this difficult to comprehend.

It is important that intended audiences (i.e., stakeholders) are able to comprehend information that is communicated to them, particularly information relevant to risk (Lipkus & Hollands, 1999). Weinstein & Sandman (1993) establish seven criteria to evaluate risk: comprehension; acceptance; dose-response consistency; uniformity; audience evaluation; and direction of communication errors. To communicate risk, Ancker *et al*. (2006) define three key goals of risk communication: 1) increase understanding; 2) change risky behaviour; and 3) encourage cooperative conflict resolution. A solution to simultaneously evaluating and communicating risk is through the use of graphics. Lipkus & Hollands (1999) utilise Weinstein & Sandman's (1993) criteria in their exploration of the use of graphic visualisation of data and developed three properties for communicating risk data in a visual manner. These properties are that: 1) graphics reveal data patterns that may otherwise be undetected; 2) specific types of graphs may automatically evoke specific mathematical operations; and 3) graphs attract and hold attention because they display more information in concrete, visual terms (unlike numbers) (Lipkus & Hollands, 1999). Table 2 summarises these key principles of communicating risk in visual terms. Integrating criteria for risk evaluation (Weinstein & & Sandman, 1993) with an understanding of the goals of communication (Ancker, et al., 2006) produces a sound framework for the visual communication of risk, as Lipkus & Hollands (1999) demonstrate.

Table 2: Key principles of visually communicating risk

Weinstein & Sandman's (1993) **criteria for risk evaluation**	**Ancker *et al.*'s** (2006) **goals of risk communication**	**Lipkus & Hollands'** (1999) **properties for visual communication of risk**
Comprehension	Increase understanding	Graphics reveal data patterns that may otherwise be undetected
Acceptance	Change risky behaviour	Specific types of graphs may automatically evoke specific mathematical operations
Dose-response consistency	Encourage cooperative conflict resolution	Graphs attract and hold attention because they display more information in concrete, visual terms (unlike numbers)
Uniformity		
Audience evaluation		
Direction of communication errors		

In their study, which aimed to evaluate the effectiveness of graphical communication against textual communication of risk through the examination of attentional processes and cognitive workload, Smerecnik *et al*. (2010) observed the behaviour of participants' eyes to determine cognitive workload and attention spans when participants looked at graphical and textual formats of risk information. The understanding derived from Smerecnik *et al*.'s (2010) work is that graphical information automatically reveals patterns, which reduces the cognitive workload required to for information comprehension. This agrees with the views of Ancker *et al*. (2006), who contend that well designed visual displays reduce mental computation by replacing it with automatic visual perception. In events where information is complex, Smerecnik *et al*. (2010) found that there is a strong link between eye movement and attention. As graphics are more complex, they require more information encoding by viewers than if they were looking at text – this was established by Smerecnik *et al*. (2010) who observed longer eye fixation durations when participants in their study looked at graphics than if they looked at text. Smerecnik *et al*. (2010) conclude that graphical risk information attracts more attention and requires relatively little cognitive workload in comparison with textual information. This indicates that audiences take the time to better comprehend the information that is communicated to them visually than if it were communicated using text.

In addition to Smerecnik *et al*. (2010) numerous authors (McInerny, et al., 2014; Ancker, et al., 2006; Spiegelhalter, et al., 2011; Lipkus & Hollands, 1999) explore the feasibility and use of graphics to communicate information. Communicating information visually using graphics is important for exploring information as well as generating understandings of subject matters, which may be intangible (McInerny, et al., 2014). Lipkus & Hollands (1999) argue that visual displays can be used either in place of numerical information or to support them for the communication of risks. Spiegelhalter *et al*. (2011) supports this argument, stating that audiences respond well to multiple types of display of the same information (not necessarily replacing information). Furthermore, according to Smerecnik *et al*. (2010),

there is a consensus that graphical formats of information in conjunction with textual information is more effective in accurately communicating risk related information than purely textual information.

When an audience fails to understand what is being visually communicated to them, it may lead to them perceiving information as non-credible or persuasive (Ancker, et al., 2006). This should be viewed as a shortcoming in the design of the graphic rather than a shortcoming of the audience as there may be other factors (such as education levels) which hinder the audience's ability to comprehend the information. Consequently, Ancker *et al*. (2006) explains that graphical elements that distort perspectives in any way from the probability of the outcome is unethical, particularly when dealing with the probability of risk. The influence of the designer is highlighted here. Designers of graphical communication can influence the perceptions of their audiences using bias – either intentionally or unintentionally (Ancker, et al., 2006). Spiegelhalter *et al*. (2011) describes this phenomenon as framing. Framing occurs when information is described in a biased way which elicits a distorted version of the truth behind information to the audience (Spiegelhalter, et al., 2011). For example, a food product can either be advertised as containing 5% fat, or advertised as being 95% fat free to attract more sales based on the 'selling point' that the product is healthier. McInerny *et al*. (2014) state that design of a graphic that connotates any bias in data is referred to as poor design. Poor design is also associated with disinterest in data sources (McInerny, et al., 2014). To overcome this, designers must present both biases to the audience at the same time (Spiegelhalter, et al., 2011), allowing the audience to independently develop a perception, and record data sources for queries in the future and enable innovative reproduction (McInerny, et al., 2014).

Smerecnik *et al*. (2010); McInerny *et al*. (2014); and Spiegelhalter *et al*. (2011) further demonstrate important considerations for developing graphical visualisations of information. Smerecnik *et al*. (2010) explain that the format in which risk (or information in general in this case) is communicated influences an audience's comprehension of the information. This is especially important as it consequently impacts decision-making processes (Smerecnik, et al., 2010) and is relevant in the case of mine closure planning as there are many stakeholders involved. McInerny *et al*. (2014) emphasize the fact that visualisations are not reality – they are purely representations of data that is derived from a host of transformations, filters, and visual encodings that produce styles and storylines of a visualisation. However, McInerny *et al*. (2014) state that there are consequences of turning data into a visualisation. Consequences include the fact that it may alter the prominence and interpretation of particular values, it can produce undesirable clustering and layering effects, or cause an audience to deduce unintentional secondary patterns (Harris & Weiner, 1998; McInerny, et al., 2014). To avoid this, Spiegelhalter *et al*. (2011) state that styles and storylines must lack clutter, have clear lines, and have colour that has been carefully composed so that the visualisation is clearly comprehendible.

Critical to the communication of information is the choice of the type of graphic used. According to Spiegelhalter *et al*. (2011), suitable chosen graphics summarise data, illuminate hidden patterns, gain and hold attention, enliven information, and inspire the viewer. Ancker *et al*. (2006) explains that the strategic choice of graphics that are used can appeal to characteristics of viewers (i.e., likes and dislikes). In addition, the more attractive that a depiction is, the more likely it is that people will believe

that it represents the whole truth rather than embodying a construction of limited judgement and knowledge (Spiegelhalter, et al., 2011). Based on these arguments, it should be noted that graphical visualisations of data should be designed as attractive and informative while expressing its own contingency and limitations. Ancker *et al*. (2006) state that the best design of a graphic which communicates information depends on the purpose of the communication. Therefore, the intended audience as well as their ability to comprehend the communicated data must be considered.

2.3. Interactive Multimedia

Conventional forms of communicating scientific information primarily focusses on an explanatory method of communicating figures that summarise information (McInerny, et al., 2014). However, McInerny *et al*. (2014) propose an alternative to this in the form of the production of 'exploratory' knowledge interfaces. Exploratory knowledge interfaces enable audiences to comprehend information while interacting with it – a process of 'learning by doing' (McInerny, et al., 2014). According to Stretcher *et al*. (1999), interacting with information correlates with a higher degree of information processing (especially among younger populations). In their in-depth analysis, Stretcher *et al*. (1999) present strong arguments for the use of interactive multimedia for the communication of risk. With reference to communicating risks, interactive multimedia is advantageous as it encourages interactivity, is adaptive, and allows for assessments to be made (Stretcher, et al., 1999). The dynamism of interactive multimedia enables audiences to separate major risks from minor risks as well as differentiate between suspected and proven, and controllable from uncontrollable risks (Stretcher, et al., 1999). This is done through the simplification of uncertainty as it is presented as meaningful graphics (Stretcher, et al., 1999). Conversely, McInerny *et al*. (2014) state that interactive visualisations should be able to adapt to the needs and characteristics of individual end users. Stretcher *et al*. (1999) explain that interactive media has the potential to do this as users of an interactive multimedia programme can weigh their own attitudes toward potential outcomes using the available database to inform them (Stretcher, et al., 1999).

Providing accessibility to information at a large scale is a difficult undertaking which is influenced by physical distance between audiences and information sources (Stretcher, et al., 1999). Interactive multimedia enables strong communication of information to mass populations at the same time as providing this information at the level of the individual (Stretcher, et al., 1999). Thus, Stretcher *et al*. (1999) advocates for the digitization of multimedia sharing and the use of the world wide web (i.e., the internet). Digital sharing of multimedia is a more efficient way to communicate risk, while sharing data via the internet enables accessibility to a larger audience that may relate to the information being shared (this also closes the so-called 'information gap' between higher and lower classes of society, reducing overall risk) (Stretcher, et al., 1999).

2.4. Cross-discipline Collaboration

It is clear that collaboration across disciplines is needed for the development of effective visual communication of information to audiences. Data visualisation offers an opportunity to support an entire information pipeline – from data exploration to assessments and drawing conclusions (McInerny, et al., 2014). Different visualisation tools and expertise across the spectrum of research fields should be

integrated to formulate the appropriate information strategies and communication (McInerny, et al., 2014). Ancker *et al*. (2006) emphasises the importance of incorporating qualitative research in the development of the correct type of visual communication (although care must be taken to not overly rely on the input of participants as this can lead to graphics that exhibit poor quantitative judgements). Spiegelhalter *et al*. (2011) further states that there should be collaboration between the artistic and scientific fields so that information is conveyed with more accuracy in an understandable manner. Lipkus & Hollands (1999) emphasise the importance of cross-discipline collaboration with specific reference to risk evaluation and information communication due to the multi-disciplinarity characteristics of risk itself.

2.5. User Experience Design

While the motivation for developing the Atlas is academic in nature, developing the end product is a creative undertaking. An online application such as the Atlas requires careful consideration of the end users and what their experience will be using it. Baring the aforementioned principles of visual communication (see Section 2.2) in mind, consideration must be given to the User Experience (UX) of the Atlas to ensure that it functions optimally.

As with GIS, here is no formal consensus on a definition for UX (Zarour & Alharbi, 2018; Law, et al., n.d.), however, Usability.gov (2023) define UX as the understanding of the users of a particular product (the Atlas in this case), their needs, values, abilities, and limitations. UX also accounts for the goals and objectives of the developer of the product (Usability.gov, 2023). In terms of a definition of UX relevant to web application designs such as the Atlas, Gualtieri (2009, p. 2) defines UX as:

“Users’ perceptions of the usefulness, usability, and desirability of a Web application based upon the sum of all their direct and indirect interactions with it.”

Gualtieri (2009) identifies three facets characteristic of good UX design: usefulness, usability and desirability. Usefulness refers to the ability of a user to achieve their goal using a particular product (Gualtieri, 2009). For example, a goal of a user of the Atlas may be to identify potential opportunities for post-closure land use development. Usability refers to how easily a user can achieve their goal using a particular product. For example, the usability of the Atlas would be the ease at which users can identify post-closure land use opportunities using the data that it contains. Desirability refers to the overall enjoyment of a particular product by a user. For example, the data visualisations in the Atlas would be attractive to users, prompting enjoyment when using it. To successfully integrates these facets into a particular design, Gualtieri (2009) stipulate four best practices:

1. *Become the users* to understand how to design for them;
2. *Design first* to avoid leaving UX to chance;
3. *Trust no one* – test to make certain that users are satisfied; and
4. *Inject UX design* into software development life-cycle processes.

Table 3 below summarises how these best practices can be achieved by outlining dos and don’ts associated with the application of each best practice, and the respective pitfalls associated with them, as discussed by Gualtieri (2009).

Table 3: Best Practices for UX design; how to implement them; and their pitfalls (Gualtieri, 2009).

Best Practice	Dos	Don'ts
Become your users	• Listen to user needs; • Observe users in their natural habitat; • Create personas; and • Empathise with users.	• Don't assume that developers already understand the user; • Don't just listen; observe; • Don't confuse business stakeholders with users; and • Don't confuse requirements gathering with user research.
Design first	• Serve business goals by serving user goals; • Find and grow design talent; • Design for change; • Know your constraints; • Design for differences; • Borrow inspiration from other designs; and • Start with low-fidelity prototypes.	• Don't forget to design for all aspects of the user experience; • Don't think tools can design for you; • Don't ignore the user research; • Don't lock into a design too soon; and • Don't rush to write code.
Trust no one – test	• Settle irreconcilable differences through testing; • Take a shortcut with expert reviews; and • Test continuously.	• Don't just test for usability; • Don't forget to test for reliability; and • Don't forget to test for security.
Inject UX design into your software development life cycle	• Educate everyone on the team about what UX is and why it is important; • Find a leader who will elevate and drive UX design; • Prioritise initial efforts on projects where you can make a big impact; • Provide incentives to application development teams; and • Transform your application development process to include UX design.	• Don't make UX design prohibitively expensive; • Don't just throw design over the wall; and • Don't fall back to old ways.
Next practices[2]	• Use immersive development methodology[3]; and • Empower designers and end user to assist in development.	

[2] Practices that development professionals should focus on once the four basic best practices have been mastered (Gualtieri, 2009).
[3] A combination of application development with UX design. Application design and UX design are made to be the core of projects, which are approached with a creative perspective (Gualtieri, 2009).

2.6. Creative Technology

Mader & Eggnik (2014) propose the concept of Creative Technology (CT) – a multidisciplinary design discipline – to improve the quality of life through product and application design that builds on information and communication technology. The design process hosted by CT consists of four phases: 1) ideation; 2) specification; 3) realisation; and 4) evaluation (Mader & Eggnik, 2014). Mader & Eggnik (2014) emphasise that these phases contain core elements of the classical approaches to design processes, namely Divergence[4] and Convergence[5], and Spiral Models of the design process. Figure 2 illustrates a detailed design process of CT. The following sections describe the four phases of Creative Technology as described by Mader & Eggnik (2014).

2.6.1. Ideation

With CT, technology can be used as a starting point for ideation (referred to as 'tinkering'), just as a design question in the form of a product idea, an order from a client or creative inspiration can be used as a starting point for other design discipline (CT is not limited to using technology as a starting point – it is merely an additional option). The goal of tinkering is to identify innovative applications for existing or new technology – bridging the gap between technology and user needs. In a phase of ideation for a CT design process based on technology, a potential user is presented with an initial prototype or mock-up of a technological idea. Users and/or experts are also interviewed to characterise their needs, describe problem settings and provide requirements for the envisaged design. Experience, interaction and a service and business model ideas are also part of the result (Mader & Eggnik, 2014).

2.6.2. Specification

During the specification phase, various Beta versions of the intended design product are experimented with. Short-term evaluation also takes place during specification, with the product being developed on an iterative basis with due consideration made for feedback on its design. The intention of this is to understand the experiences of users when using the various iterations of a particular design and what their demands are. The various Beta versions of a product are presented to users and developed according to their feedback in conjunction with the expertise of the designer. It is important to note that UX is the main focus during specification (Mader & Eggnik, 2014).

2.6.3. Realisation

During realisation, engineering design methods – characterised by decomposition of the start specification, realisation of the components, integration of the components, and evaluation. Evaluation referred to here is distinct from the CT phase of evaluation. In realisation, evaluation refers to the validation of the end product to determine if design specifications are met. Functional testing of a design is included in realisation (Mader & Eggnik, 2014).

[4] A design space is opened up and defined, allowing for the exploration of a wide range of information (Mader & Eggnik, 2014).
[5] The process of reduction of the design space to identify a suitable solution (Mader & Eggnik, 2014).

2.6.4. Evaluation

Functional testing may also be included in evaluation if earlier functional discrepancies or requirements are not addressed. Most importantly, however, evaluation of the product is done with consideration of the criteria of original requirements as identified during ideation. This is usually done through further (final)user testing of a designed product (Mader & Eggnik, 2014).

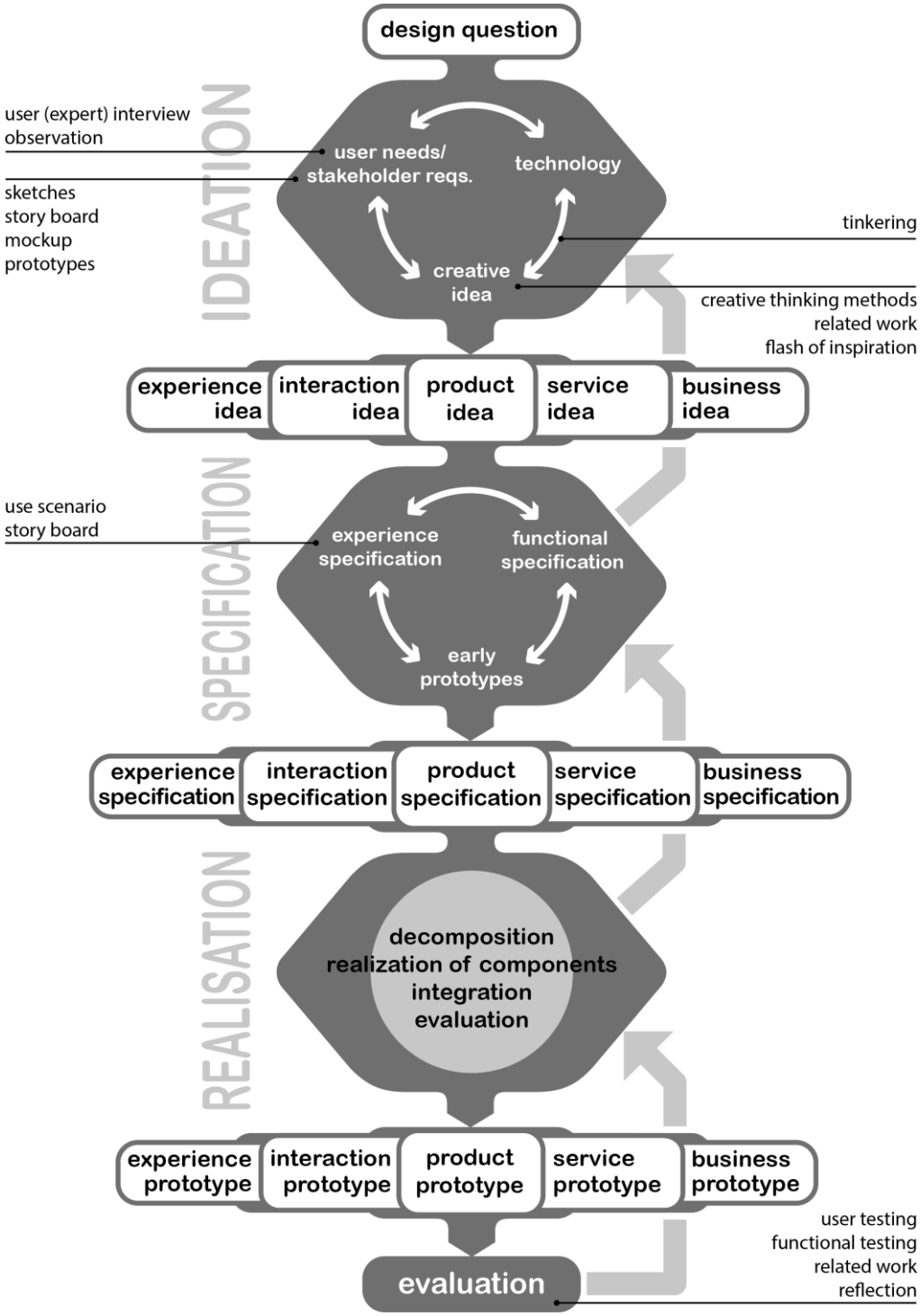

Figure 2: The Creative Technology Design Process (Mader & Eggnik, 2014).

2.7. User Testing

It is clear that user testing and feedback play a pivotal role in developing any sort of application or software design. Drawing on the explanation of UX by Gualtieri (2009) and the design process outlined by Mader & Eggnik (2014), Figure 3 (adapted from Parenzo (2023)), illustrates step-by-step process of continuous user testing that can be applied. During the pre-launch phase[6] of app development, the following steps of user testing are considered by Parenzo (2023):

2.7.1. Prepare and Plan

Develop a roadmap for a usability test – the usability test plan, which typically consists of the following:

- The test's purpose and objectives;
- Participant/user characteristics;
- Determination of the usability testing method;
- A task-list that a participant/user is able to complete;
- Test environment, equipment, and logistics;
- Expedition of the test facilitator's role;
- Identification of data to be collected;
- Measures of evaluation; and
- Report content and presentation.

2.7.2. Define Clear User Testing Goals

When conducting user testing during the development phase, identify:

- User needs;
- Similar products already in use; and
- Issues regarding the design that users need help with.

Defining user testing goals requires conversation with users/potential users before a functional prototype is developed.

2.7.3. Build a Working Prototype

Build a prototype that performs the desired functions of the end product. Users are meant to test the functionality of the product at this stage.

2.7.4. Select between In-person and Remote Testing

In-person and remote testing each have their own advantages and disadvantages. In-person testing allows participants to raise questions in real time and help developers grasp a clearer image of a user's experience. However, in-person testing can be time consuming. With remote testing (which is preferably under restricted budgets), it is less obvious. Remote testing can either be moderated or unmoderated. Moderated remote testing allows for the developer to be present when the user tests the product. Users

[6]The stage of app development that occurs before the official launch of a software development/application.

may ask questions in real time. With unmoderated remote testing, users may still ask questions at a later stage and won't feel the pressure of the developer observing them while they test the product.

2.7.5. Participant Selection

Participants must:

- Represent target users;
- Own the device which the product works on (e.g., a laptop or smartphone);
- Be available for testing; and
- Provide consent to participate in the research.

2.7.6. Set Up the User Testing Environment

Identify a suitable room or remote meeting environment to conduct the user testing. Be sure to understand how all technical tools work before testing takes place.

2.7.7. Test your "Test"

This is recommended to determine whether:

- The planned timeframe is suitable;
- The technical setup works; and
- Instructions to be given to participants are clear and consistent.

2.7.8. Conduct the User Test

Provide short scenarios to participants and ask them to use the product to navigate the scenario through a series of tasks. Do not disclose the length of each task. Participants must be encouraged to ask questions and provide comments.

2.7.9. Analyse and Act on the Results

Analyse the results of the testing and all comments and questions from participants with careful attention to detail. Ask participants what they remember about the overall usability of the product. Clear explanations indicates a sound structure.

It is recommended that further testing takes place after a product is launched. This would allow for further development and improvements to be made, enabling the product to remain relevant and up to date (Peranzo, 2023). However, this may be beyond the scope of this study.

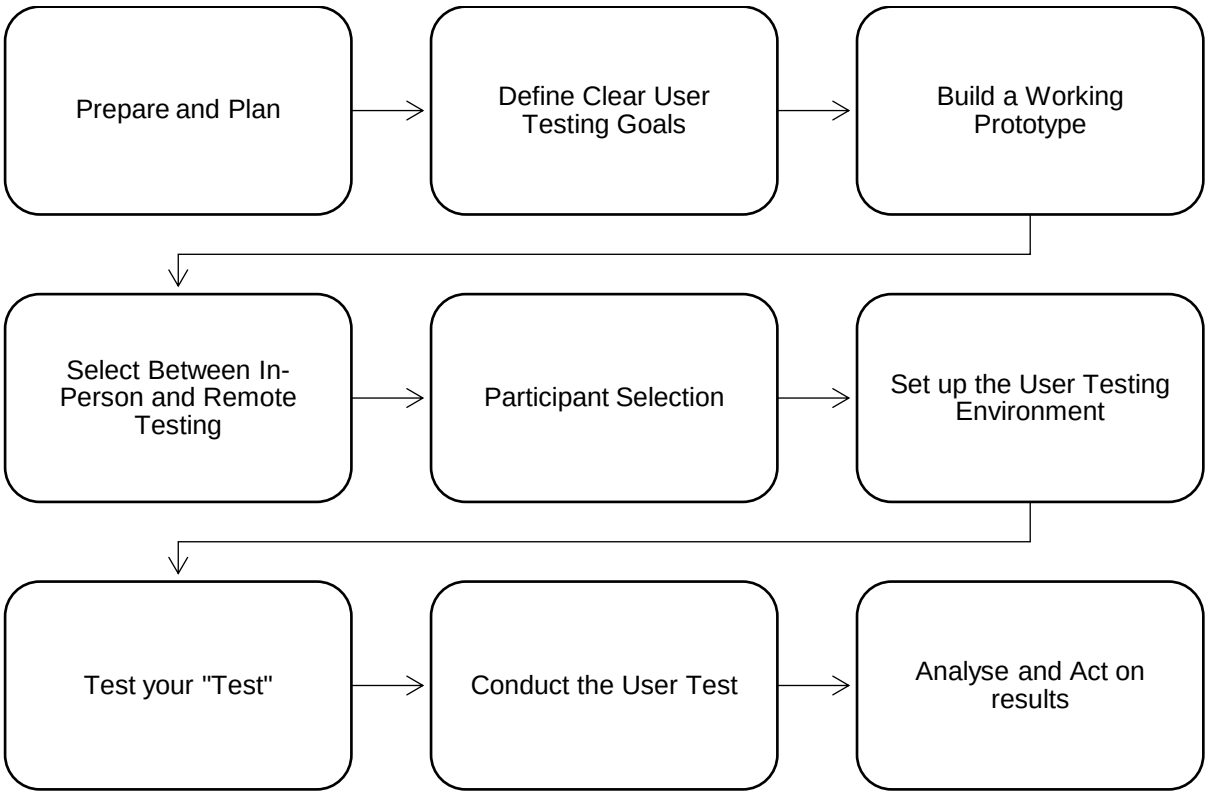

Figure 3: Method for User Testing as adapted from Peranzo (2023)

2.8. Geographic Information Systems

Geographic Information Systems (GIS) are information systems that derive data from real world features and displays them in a symbolical interpretation (Maguire, 1991). There is no definitive definition of GIS, however a few definitions have been stated in literature. One of the earliest definitions of GIS was stated by Burrough (1986, p. 6), who describe GIS as:

"…*a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world*".

Other definitions of GIS include that of Parker (1988, p. 1547), who state that GIS is:

"…*an information technology which stores, analyses, and displays both spatial and non-spatial data*".

Smith *et al*. (1987, p. 13) provide a more detailed definition of GIS, describing GIS as:

"…*a database system in which most of the data are spatially indexed, and upon which a set of procedures operated in order to answer queries about spatial entities in the database".*

Koshkariov *et al*. (1989, p. 259) further comments that GIS is:

"…*a system with advanced geo-modelling capabilities*".

While it is evident that there are multiple definitions of what GIS is, Maguire (1991) highlights one common feature of all definitions of GIS: GIS are systems which deal with geographic information. It can best be described as a system which integrates a collection of computer hardware, software,

geographic data, and information processing and applications which operates in an institutional context (Maguire, 1991; Johnson & Johnson, 2001). They are tools which integrate predeveloped ideas from various different disciplines (Maguire, 1991). The intended purpose is to efficiently capture, store, update, facilitate analyses, and display all forms of geographically referenced information (Johnson & Johnson, 2001).

2.8.1. GIS as a Unique Information System

According to Maguire (1991), the characteristic of GIS which sets it apart from other information systems is that it has the ability to analyse spatial data. It does this by presenting reality as a series of geographical features that are defined in accordance with geographical (locational) and attribute (non-locational) data (Maguire, 1991). This is done by effectively managing large amounts of data by capturing, storing, handling and geographically integrating the data from different programmes, sources and sectors (Johnson & Johnson, 2001)). However, according to Harris & Weiner (Harris & Weiner, 1998), this is a potential weakness of GIS as data that does not have a geographic identification cannot be referenced in GIS. Nonetheless, GIS enables continuous systematic collection and analyses of data (Johnson & Johnson, 2001). In their work on developing a GIS tool to monitor and manage epidemics, Johnson & Johnson (2001) argue that data produced in the form of maps are more effective for the communication of information when compared to other graphics such as tables and/or charts. Furthermore, the nature of GIS enables the presentation of spatial information, which can cover a large geographic area which impacts a large mass of people, at the level of individual occurrence (Johnson & Johnson, 2001) – a key feature of interactive multimedia (Stretcher, et al., 1999).

The key reason for the success of GIS is the use of Geographic references (Maguire, 1991). Various datasets are linked together through the use of implicit (mountains, administrative boundaries etc.) and explicit (longitude/longitude) geographic references (Maguire, 1991). This data can then be used to perform overlay analyses – a unique feature of GIS. Information from different datasets are overlayed which allows for multicriteria modelling (Johnson & Johnson, 2001). In other words, relationships between different layers of information can be studied as they are visually layered on top of each other. Assessments can then be made from the deduced information.

2.8.2. GIS and Society

Malczewski (2004) explains that GIS technology has historically been criticised by social scientists due to issues with its impact on equity, justice, privacy, accuracy, accessibility, and quality of life. The result was a divide between the techno-positivist (proponents) of GIS and the social scientists (opponents) of GIS (Malczewski, 2004). Developments in the field has led to a consensus in focusing on the relationship between these two facets. According to Lechner *et al*. (2019), GIS has the potential to be utilized as a common platform in which data from biophysical and social science disciplines can be integrated using qualitative and quantitative methods and shared locational data that is communicated through interactive visualisation platforms.

2.8.2.1. Data Types

GIS does not produce data, it integrates it (Harris & Weiner, 1998). It is a platform whereby diverse types of data are linked in order to interpret unique challenges (Lechner, et al., 2019). Biophysical and social science disciplines can be facilitated by a GIS platform by integrating quantitative and qualitative methods and presented using locational data and interactive visualization platforms (Lechner, et al., 2019). Therefore, input data for a functioning GIS needs to be carefully considered to provide optimal functionality and analyses.

According to Harris & Weiner (1998), basing GIS entirely on 'facts' (i.e., quantitative evidence) with lesser conceptualisation of data in relation to knowledge has resulted in an 'anti-geography' perception of GIS by critics. On one hand, there is no doubt that factual evidence is an important facet of GIS – quantitative components in the form of spatial data allows spatial dimensions to be considered to aid assessments of how, when, why, and where 'location' is relevant (Lechner, et al., 2019), which is a critical niche that GIS has over other information systems. On the other hand, Harrison & Weiner (1998) explain that spatial information on its own does not always accurately represent the real world. Local level qualitative data and information is required to depict accurate representations (Harris & Weiner, 1998). Malczewski (2004) emphasises that integrating 'hard' information (factual data and information) and 'soft' information (opinions of interest groups and decision makers) enables data to be viewed from multiple perspectives and serve as a basis to conduct many 'what-if' scenarios that can lead to better informed decision making. This is a critical aspect, particularly in the mining sector. Lechner *et al*. (2019) explain that mining companies use and rely on qualitative information when interacting with stakeholders as it extends to interpreting their perspective and expectations. According to Harrison & Weiner (1998), this method is generally less used in GIS due to the difficulty in integrating qualitative information with GIS. However, developments in GIS software, such as GIS products offered by Esri, has made this integration easier to achieve in recent times (Esri, n.d.).

Harrison & Weiner (1998) propose the concept of community integrated GIS. Community integrated GIS acts as a forum in which issues, information, alternative perspectives, and decisions resolve (Harris & Weiner, 1998). Essentially, community integrated GIS presents itself as a form of stakeholder engagement to establish guidelines under which a GIS should be developed. Lechner *et al*. (2019) apply a broader concept to the development of GIS – spatially integrated social sciences. Spatially integrated social sciences include qualitative GIS approaches (such as geo-ethnography and geo-narratives) to combine social data with GIS (Lechner, et al., 2019). This builds multidisciplinary perspectives which reference qualitative knowledge to identify findings within other data (Lechner, et al., 2019). A key aspect of this approach is that quantitative and qualitative outputs must work in tandem with each other to communicate deeper conflicts between different disciplines (Lechner, et al., 2019). Lastly, Malczewski (2004) proposes the Multi-Criteria Decision Making (MCDM) framework. MCDM is a process whereby spatial and aspatial data (inputs) are combined and transformed into resultant decisions (outputs) (Malczewski, 2004). To do this, geographical data is utilised and the preferences of decision makers are used to manipulate the data according to specified rules (Malczewski, 2004). Malczewski (2004) does, however, highlight key issues associated with MCDM including the choice of

method for combining different evaluation criteria, standardisation of criterion maps, and the specification of criterion weights.

Incorporating both quantitative and qualitative aspects in the development of GIS enables a deeper understanding of study areas, which may be understood differently by different social groups (Harris & Weiner, 1998). Therefore, it would be hugely beneficial for people (i.e., users of a particular GIS platform) to actively be involved with the development of a GIS platform to ensure that it depicts accurate information for its intended use. However, Harris *et al*. (1995) explains that the conventional workflow in the development of a GIS platform involves the motivation of a private institution to develop an analytical tool with the help of technical experts, often disregarding knowledge outside of the technical realm that may well improve a particular project. Therefore, it is in the hands of the GIS developer to integrate suitable knowledges in the development of GIS platforms.

2.8.2.2. Accessibility

While GIS is predominantly perceived as a purely data driven operation, it has numerous interactions with society. These interactions range from the types of data used, access to this data, and the human-technology interface. This all plays a role in decision-making processes which impacts societies if GIS is used to aid decision-making processes (Harris & Weiner, 1998). Thus, it is important to carefully consider the usability and access of a GIS platform by society in the development of a GIS at all stages.

Internet access is the first hurdle when attempting to access GIS platforms. Web GIS is a powerful tool that has the potential to instantly share information to anyone in the world (Johnson & Johnson, 2001). However, access to the internet is required for this (Johnson & Johnson, 2001). In terms of the accessibility of data visualisations, Snapurd & Velazquez (2020) argue that perceivability, operability, comprehension, robustness, and findability (i.e., the ease of which information can be found) are key requirements. These are generic accessibility requirements for web content (Snaprud & Velazquez, 2020), but are applicable to the establishment of an online GIS platform.

Access to source data is what proves to be the biggest hurdle in the development of free access GIS platforms. GIS has the potential to marginalise and empower people at the same time (Harris & Weiner, 1998). While the potential for GIS to improve people's lives are immense, given its data visualisation capabilities, access to the GIS and its associated data in the first place is an obstacle to achieving its full potential. Restrictions on public access to data and the commodification of spatial data are contributors to this (Harris & Weiner, 1998). The wide-reaching capability of GIS means that it is used by many organisations, which are ultimately regulated by political powers. According to Harris & Weiner (1998), GIS is a segment of a broader political process, not an isolated technical or computational platform. While the rules which govern information sharing can be exploited by organisations who wish to commodify their data, it also contributes to the marginalisation of people and communities and hinders the potential of GIS to make far reaching impacts for development and empowerment. The success or failure of a particular GIS platform is ultimately an institutional or managerial issue (Harris & Weiner, 1998).

Following the access to source data is the use of that data to develop GIS outputs. Outputs derived from GIS operations have clear value. However, this information may come at a cost. The value of information (in GIS) is dependent on numerous factors, including context, cost of collection, storage, manipulations, and presentation (Maguire, 1991). Thus, GIS may become an asset and/or a commodity (Maguire, 1991). One such asset that is popular in today's world is Web GIS. With Web GIS, data is stored in a central server which can be accessed from various other terminals via the internet (Johnson & Johnson, 2001). Information then becomes instantly available to anyone anywhere in the world who is granted access by the owner organisation (Johnson & Johnson, 2001). For example, if a dynamic map tool, such as an online atlas, is published using Web GIS, anyone with internet connection will be able to access and use it, but only if they are granted access (usually at a cost).

The reasons behind the gatekeeping of data by organisations must also be considered due to the potential of unwanted consequences occurring. As GIS has unique 'surveillance' capabilities, it may undermine the integrity of observational ethics. Although a publicly available GIS platform should not disclose personal information (such as individual identities, addresses etc.), it does disclose specific characteristics of particular areas. The result is what Harris & Weiner (1998) point out as being a knowledge-power configuration in society that reinforces the technologies of normalisation and knowledge engineering leading to the potential manipulation of certain populations. Certain parties may utilise the available information for sinister reasons (Harris & Weiner, 1998). An example of this is when a fitness app unintentionally revealed the layout of a United States military bases in 2017 (Hern, 2018). The fitness app, which uses Global Positioning System (GPS) to track running or cycling routes, was used by soldiers to track their personal fitness around a military base. The fitness app owners published a detailed map of routes ran and cycled by people around in the world in 2017, unintentionally revealing private details of military bases that are (intentionally) not made visible on publicly available satellite imagery (Hern, 2018). This information could potentially be used by opposition forces to incite conflict. Information available on a GIS platform may also be used by local communities to evaluate the state of their own context in relation to neighbouring communities, possibly resulting in conflict with local government, private enterprises, and/or between communities (Harris & Weiner, 1998). Traditional leaders may also not want information about their communities being made publicly available due to cultural reasons (Harris & Weiner, 1998).

2.8.3. GIS and Mining

The complex anthropogenic characteristics of the mining industry cannot be fully developed with the exclusion of GIS (Andreev, 2021). It has benefits at all scales – it can be used for environmental and socio-economic risk assessments at a local scale; cumulative and strategic impact assessments at a regional scale; and for analysing industry-wide land use trends for comparative analyses of impacts across commodities, locations, and mine configurations at a global scale (Werner, et al., 2019). According to Werner *et al*. (2019), GIS is conventionally used in the mining industry during the exploration phase of a mine, for the development of EIAs, and for mine management. However, mining companies also use GIS to evaluate mining conditions; identify suitable mine models for construction; display geochemical and hydrological data; optimize the management of facilities and policing; aid

applications for mining permits; assess environmental impact; manage land titles; process closure; identify suitable reclamation activities; and improve community education (Esri, 2018). While Esri, a supplier of GIS software products, states that GIS can indeed be used for mine closure (Esri, 2018), Andreev (2021) and Werner *et al*. (2019) indicate that GIS is used primarily for the exploration and operational phase of a mine. Poole (2023) attributes the use of GIS in mine closure planning for the collation, analyses and visualisation of large volumes of geospatial and discrete data linked to closure risks, designs, costs and performance to create confidence in closure planning processes. In addition, improving the use of GIS in mine closure planning allows for an increase in the amount of detailed records of mine rehabilitation and closure which, in turn, supports the provision of solutions to key mine closure challenges such as staff turnover, changing regulator and stakeholder expectations, confidence in adequate closure cost estimates and strategy decisions (Poole, 2023). Studies that have utilised GIS to assess the impact of mining activity include that of Werner *et al*. (2019), who provide an overview of recent studies that utilise techniques to assess the impact of mining on water, land and society – all of which was established to overlap with each other – and Ruhela *et al*. (2022) who use GIS and field data to examine the spatial distribution of air and water pollution around a mining site in Chhattisgarh, India.

2.8.4. GIS for Risks and Opportunities of Mine Closure

2.8.4.1. Socio-economic Risk

From a socially based perspective, Lysaniuk *et al*. (2021) estimate population living near asbestos processing plants and mines in Columbia by using census data and GIS to establish the risk posed by the mining operations. While it is possible to use GIS in these types of risk assessments, Lysaniuk *et al*. (2021) do mention the existence of many confounding variables that were beyond the scope of their study to examine. According to Cole & Broadhurst (2020), significant changes such as mine closure has an impact on employment and local economies of mining communities. This may depend on the type of mining community impacted, as Cole & Broadhurst (2020) classify mining host communities in South Africa as either co-established cities, large mining towns, small mining towns, or pre-existing communities. The impact of mine closure in this regard may depend on the level of economic diversification of a particular mining host community (Cole & Broadhurst, 2020). Werner *et al*. (2019) state that it is difficult to cartographically illustrate deeper social and economic dynamism. Instead of studying society and economics from an external perspective, Werner *et al*. (2019) rather suggest that socio-economic aspects can be studied by using GIS as a tool to inform interviews; understand the experiences of individuals affected by mining; as a participatory mapping tool to identify culturally or historically significant areas, and/or to predict possible future land uses, which would aid economic diversification. This is in agreement with the views of Malczewski (2004), who states that GIS should be used as a tool for planning *with* the public rather than *for* the public. Although visualising the characteristics of a region in cartographic form using GIS creates an oversimplified depiction of reality, analysing a region in spatial and visual terms sanctions wider public debates and addresses communities impacted by mining who are least represented in literature (Werner, et al., 2019).

2.8.4.2. Protected Areas

The location of a mine site is an important factor when assessing possible environmental risks of mining activity and closure. The earth's minerals are static in nature (i.e., there is a finite amount of minerals in the earth, and they do not move to different locations) (Durán, et al., 2013). As a result, mining operations are built around mineral 'hot spots' which determines the extent of which supporting infrastructure is needed to be developed (Werner, et al., 2019). Surrounding areas that are not directly involved with mining processes are impacted by mining operations (Werner, et al., 2019). According to Duran *et al*. (2013), the results of a collation of studies indicate that environmental impacts of mining activity extend for tens of kilometres away from the location of mine sites. Based on this, it can be assumed that there is no clear boundary at which environmental impacts of mining are limited to (Durán, et al., 2013).

The limitation placed on the location of mines and the extension of their environmental impacts make it difficult to evaluate environmental risk. According to Werner *et al*. (2019), an impact may only be considered significant if it covers a significant area of a mine site (this can be evaluated using remote sensing technology such as satellite or drone imagery) or has the potential to exceed the boundaries of the site itself. However, Werner *et al*. (2019) also states that the extent of damages to surrounding natural ecosystems correlates with the characteristics of those ecosystems (i.e., richer ecosystems are more sensitive receptors to impacts) in addition to the proximity of a mine from the surrounding natural environment.

In their study, Duran *et al*. (2013) establish that current mining activity is less likely to be found within the boundaries of protected/conservation areas (likely due to mining activity being less likely to be established where protected areas are already present and vice versa). However, global increases in demand and prices for metals is resulting in mining being pushed into more remote regions that have not been mined in the past (Pulgar-Vidal, et al., 2010). This, coupled with the economic potential possessed by previously non-viable deposits found within or near protected areas, has affected the trend towards developing mining activity within or in close proximity to protected/conservation areas (Durán, et al., 2013). Duran *et al*. (2013) project that mining activity and protected areas will probably overlap in the future. The South African Department of Forestry, Fisheries and the Environment (DFFE) publishes quarterly updates of protected areas in South Africa.

2.8.4.3. Water

Water is an integral part of community well-being and landscape resilience (Rockström, et al., 2014). It is one of the key aspects of human survival and prosperity (Rockström, et al., 2014). Freshwater is a requirement for all living organisms and is depended on by landscape to provide ecosystem services (Rockström, et al., 2014). South Africa is particularly vulnerable country in this regard. It is a water-scarce country which has a mean annual rainfall of just 490 mm (about 50% of the global average) (Le Maitre, et al., 2019). The country also has high evaporation rates – less than 9% of rainfall reaches rivers, where most of the country's water requirements are met (Le Maitre, et al., 2019). The uneven spread of rainfall in the country means that many communities either depend on groundwater, or water

that is sourced far away (Le Maitre, et al., 2019). These factors contribute to the necessity of protecting the South Africa's water resources.

Le Maitre *et al*. (2018) have identified Strategic Water Source Areas (SWSAs) in South Africa. SWSAs are areas of land that either supply a disproportionate amount of mean annual runoff (surface water) in relation to their size; have high levels of groundwater recharge or forms a nationally important groundwater source; or meet all of these criteria (Le Maitre, et al., 2018). These areas are integral for food and water security and make valuable contributions to generating electricity for South Africa (Le Maitre, et al., 2018). These areas must be considered when planning mining operations. According to McCullough (2016), Acid Mine Drainage (AMD) is one of the biggest liabilities of mine closure planning. AMD is formed when water used for mining operations comes into contact with geochemically enriched geologies and natural water sources (McCullough, 2016). Waste landforms develop AMD due to poor waste management at closure (McCullough, 2016). Therefore, it is important to consider the location of mines in relation to SWSAs to avoid detrimental impacts resulting from AMD at the closure stage. The Water Research Commission (WRC) has mapped the SWSAs in South Africa and made this data available to the public.

2.8.4.4. Land Use Opportunities

Mapping potential post-closure land use opportunities is one of the success criterion recommended by the ICMM (International Council on Mining & Metlals, 2019). There are a variety of ways to map future land use using GIS. Dawid & Bielecka (2022) use a GIS algorithm to model predicted land use and land cover change using open-source historical data. However, according to Malczewski (2004), using artificial intelligence such as this is not a verifiable means to establish future land use due to the lack of real-world application. It is not feasible to predict land use changes based on organic alterations as drastic changes in land use, such as pursuing a different development on land that was previously used for mining activity, cannot be based on historical land use change – a conscious decision is taken by humans to alter the landscape. The approach taken by Servou *et al*. (2021) is more suitable in this instance. In their work, Servou *et al*. (2021) establish a specific criterion to assess suitability for alternative land uses for the Ptolemais mining area, Greece. Their criteria consist of the following: 1) slope gradient; 2) reclamation works already completed; 3) slope aspect; 4) proximity to road network; and 5) proximity to residential areas (Servou, et al., 2021). It is a simple Boolean operation in conjunction with buffers and overlays (i.e., an area is examined as either having the suitable characteristics, not having it, how far away a planned development is from stipulated features, and whether or not it is situated within other areas, like within a protected area, for example) (Servou, et al., 2021). The criteria used can be altered in accordance with development type. For example, Duvenhage *et al*. (2020) stipulate suitability and exclusion criteria for the development of areas in South Africa to optimise solar power potential. Suitability criteria for optimal solar power generation included Direct Normal Irradiation (DNI) levels, distance from required infrastructure, and comparing planned development areas with the condition of existing concentrated solar power developments in South Africa (Duvenhage, et al., 2020). Exclusion criteria included rivers and water bodies, slope aspect, ecological conflict, and economic (land use) conflict (Duvenhage, et al., 2020). Servou *et al*. (2021)

stipulate that the proximity to roads is a very important characteristic for agricultural developments – the closer the agricultural development is to a road, the easier it is for people living in rural areas to access it. Altitude should also be considered for agricultural developments as higher altitudes are exposed to lower temperatures and higher wind speeds which limit the type of agricultural activities that are suited to take place (Servou, et al., 2021). Overlaying features and maps in this way is central to the GIS applications (Malczewski, 2004).

2.8.5. GIS in the Context of Mine Closure in South Africa

Mining towns were initially developed in South Africa as a result of the migrant labour system during the colonial and apartheid era (Cole & Broadhurst, 2021). Black mine workers were housed in compounds far away from their hometowns to be close to their place of employment (i.e., the mines) (Marais, et al., 2018). These areas were underdeveloped and expanded into informal settlements following the surrender of government influx control in the 1980s (Cole & Broadhurst, 2021). Today, there are 360 diverse communities, comprising of 6 million residents, that host large-scale mining across South Africa (Cole & Broadhurst, 2021). According to Cole & Broadhurst (2020), 52 of these communities are highly dependent on mining. The coal industry hosts 42% of this population, platinum hosts 16%, and the diamond industry hosts 8% (Cole & Broadhurst, 2021).

Communities are vulnerable to mine closure because it has significant impacts on the socio-economic state of mining communities as well as potentially detrimental impacts on the surrounding environment (Besa, et al., 2019; Edwards & Maritz, 2019). Mining companies are mandated to offer socio-economic development of their host communities by the Mineral and Petroleum Resource Development Act 28 of 2002 (MPRDA). As mining offers employment to communities in this regard, mine closure may lead to an influx of unemployment and poverty if economic and skills diversification is not implemented in mine closure strategies and if the environment is ineffectively rehabilitated (Nel, et al., 2003; Cole & Broadhurst, 2020).

The South African legislation recognises the necessity of sustainable mine closure planning (Mineral and Petroleum Resources Development Act, No. 28 of 2002). However, determining precise risks of closing a particular mine and post-closure land use opportunities for particular areas may prove difficult given the unique scenarios of every mining region in South Africa. The South African Department of Mineral Resource and Energy (DMRE) drafted a National Mine Closure Strategy Plan in 2021, which advocates for mine closure planning to take place at a regional scale by clustering mining areas according to mineral type (see Figure 4). The aim of this strategy is to govern each mineral cluster under individual governing bodies to ensure the well-being of all stakeholders.

Whether regional governance is an effective means of governing mine closure or not can be contested. However, the use of a GIS platform to inform decision-makers and stakeholders may aid the development of robust closure planning. The first obstacle to be overcome is internet access. The World Bank indicates that 70% of South Africans make use of the internet as of 2020 (The World Bank, 2022). This is set to increase over the next few years as Statista, a provider of market and consumer data, projects that over 90% of South Africans will be using the internet by 2027 (Statista, 2022). However, in

their work on measuring progress toward the Sustainable Development Goals (SDG) in South African mining host communities, Cole & Broadhurst (2021) indicate that only 34.4% of South Africans living in mining host communities had access to the internet in 2011 (according to Census 2011). The lack of internet may limit the number of stakeholders residing in mining host communities from being able to access an online GIS platform and subsequently using its capabilities in mine closure planning stakeholder engagement processes.

The second obstacle that needs to be overcome, and that follows the ability to access the internet, is how well stakeholders are able to comprehend the information shared on the GIS platform. While the principles discussed in Section 2.2 regarding data visualisation should be applied, the South African context should be considered in relation to how best to convey information. Statistics South Africa (StatsSA) indicate a 95.7% literacy rate of South Africans between the ages of 15 to 34 as of 2019 (StatsSA, 2022). Furthermore, the literacy rate of South Africans between the ages of 35 to 64 is 85.8% as of 2019 (StatsSA, 2022). Upper secondary and secondary school completion rate is 71.9% and 68.3% respectively as of 2019 (StatsSA, 2022). While this data may seem optimistic, Cole & Broadhurst (2021) indicate that only 42.2% of people (aged 20 and above) living in South African mining host communities had a National Qualifications Framework (NQF) level 4 qualification (i.e., completed Grade 12 or have a National Technical Certificate (NTC) from a technical college in 2011. Based on current literacy and education levels in South Africa, care must be taken to design a GIS platform that can be interpreted without high level training. While McInerny *et al*. (2014) states that not all stakeholders have the necessary expert training to comprehend visually communicated information, South African mining host communities may not have basic level training in the first place. According to Lipkus & Hollands (1999), successfully communicating risks requires an understanding of the intended audience's characteristics. Therefore, developing a GIS platform to communicate information to mining host communities should be developed with a basic user interface with simple data visualisations that communicate accurate information about mine closure risks and post-closure land use opportunities.

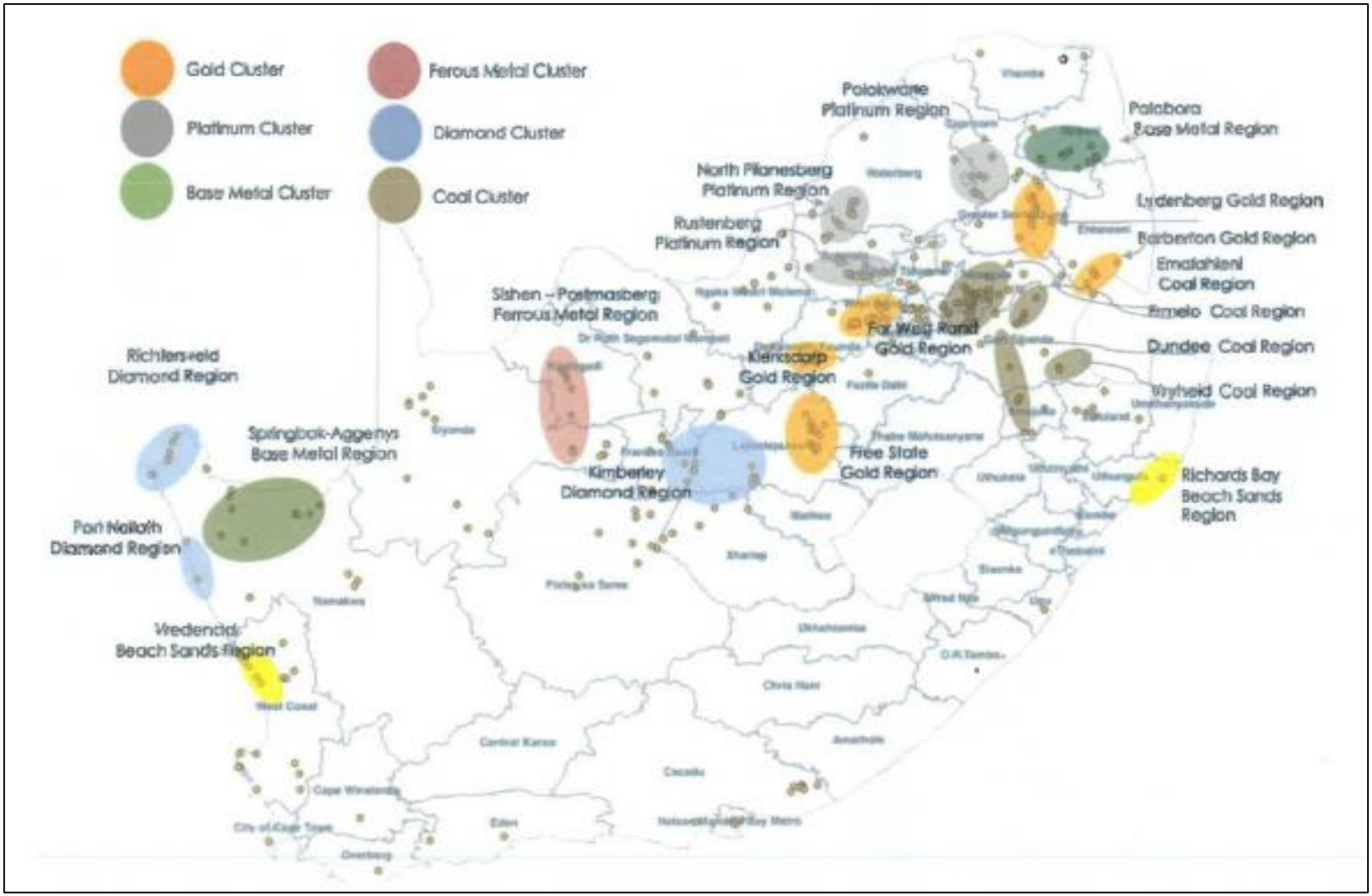

Figure 4: Regional Mining Clusters as defined in the Draft National Mine Closure Strategy (Department of Mineral Resources and Energy, 2021).

2.8.6. Existing GIS Tools

2.8.6.1. Internationally Applied GIS Tools

There are various online GIS tools that share data pertaining to the mining industry across the world. Kauppila *et al.* (2019) mention the use of GIS as an aspect of a broader online mine closure data depository, Closurematic – a digital planning and management tool for continuous mine closure (Closurematic, n.d.). The authors do not specify the explicit use of GIS to identify risks and opportunities. Kaupilla *et al*. (2019), on the other hand, attribute their use of GIS to the identification of physical environmental aspects which require rehabilitation as a result of mining activity. The Umwelt Bundsmant (UBA) (German Development Agency) developed a more interactive GIS database. The UBA mapped 100 major copper, iron ore and bauxite mine sites across the world and assessed them for environmental hazard potentials (Umwelt Bundesamt, 2023). The results of the UBA's study have been published in an online interactive map with various functions. It must be noted that their interactive map did not contribute to the assessment of environmental hazard potential of the mines. Rather, the interactive map is a depository of the data produced from their study.

The Atlas of Australian Mine Waste is a GIS tool that provides stakeholders and interested and affected parties with information pertaining to mine tailings, waste rock, smelter residues and related mine waster materials in Australia (RMIT University, Australian Government & The University of Queensland Australia, 2023). It enables the identification of potentially new opportunities for critical minerals supply from secondary sources and helps support sustainable economic recovery of critical minerals extraction from mine waste in addition to the appropriate management thereof (RMIT University, Australian Government & The University of Queensland Australia, 2023). This tool is an effective means of facilitating analyses and making information accessible, however it is restricted to the aspect of mine waste. It is also restricted to displaying point features rather than incorporating polygon features regarding environmental characteristics that offer considerations for risk management.

2.8.6.2. Existing GIS Tools in South Africa

There are various online GIS tools that are freely available specifically for the South African context. CapeFarmMapper is an online mapping tool designed to assist with spatial information queries and decision making (Western Cape Department of Agriculture, 2022). While it is designed for use in the agricultural sector, the spatial datasets contained within the mapping tool, such as water resources and biodiversity, is relevant to the mining industry and is often used by consultancy firms. While some data hosted by CapeFarmMapper is presented at a national scale, the data is mostly limited to the extent of the Western Cape province.

South African National Biodiversity Institute (SANBI) Biodiversity GIS (BGIS) contains a host of datasets for South Africa pertaining to the natural environment. In addition to datasets exclusively pertaining to South Africa's biodiversity, BGIS also hosts spatial data on the 2012 Mining and Biodiversity Guidelines, which highlight areas that are legally protected and have high biodiversity importance (South African National Biodiversity Institute, 2022). Unlike CapeFarmMapper, SANBI BGIS allows users to either

download the datasets or view them within the built-in map viewer (South African National Biodiversity Institute, 2022).

MinAgri – a collaborative effort between Mineral Council South Africa and Agri SA – aims to promote and sustain fair trade-offs between South Africa's mining and agricultural sectors (MinAgri, 2023). One of the key outputs of the collaboration was the development of an online information platform which includes an online atlas. The online atlas displays static GIS imagery of key municipal level data as well as facts and figures of the mining and agricultural sectors (MinAgri, 2023). MinAgri's atlas is a classic example of integrating information from different sources with an aim of revealing new perspectives of the data when they are combined.

The South African Mine Water Atlas contains data pertaining to the vulnerability of ground and surface water resources to mining activity in South Africa. The data is overlaid with locations of mining and refining activities with the aim of understanding the interactions between potential mining activities and water. It is intended to be used by mining companies, investors, government departments, civil society and academics (Water Research Commission, 2018). The South African Mine Water Atlas is an exceptional tool for understanding the impact of mining activity on water resources in South Africa, but is limited in terms of risk identification given that there are many other influencing factors on risk associated with mining activity.

AmaranthCX (2023) released a comprehensive online 'mining map'. The map contains datasets for over 900 mines and mining areas in South Africa, with the main selling point of the map being the demarcation of farm portions allocated to each mine (AmaranthCX, 2023). In addition to streamlining the exploration phase of mining projects, knowing which farm portions are allocated to each mine may aid post-closure land use planning. The extent of the land under the mine's jurisdiction provides information for the selection of post-closure land use.

2.9. Summary of Literature Review

This section provides a comprehensive review and synthesis of literature pertaining to the development, use and implementation of GIS in the context of mine closure. Firstly, a short discussion on mine closure is given. Secondly, the use of data visualisation, methods pertaining to it, and its implementation is discussed. A comprehensive discussion on GIS is then provided followed by the application GIS in the mining industry, particularly in the context of mine closure. The literature discussed is then applied to the context of mine closure in South Africa. While many key principles relevant to the development of a GIS Atlas tool to aid mine closure decision-making are discussed, careful consideration must be made for the South African context. It is imperative that, should a GIS Atlas tool that assists mine closure in South Africa be developed, it must be done with the input of various stakeholders, including local communities and experts, while also considering the key principles of data visualisation and GIS. If this is successfully executed, a GIS Atlas tool that assists all stakeholders and supports legislation relevant to mine closure in South Africa will be developed.

CHAPTER 3

3. Methodology

A transformative research paradigm is utilised for this study. A transformative research paradigm utilises a mixed methods approach to dismantle myths and empower people to change society (Mertens, 2007). It combines quantitative and qualitative methods. The fundamental purpose of GIS is to unveil underlining insights by integrating diverse data sources (Spiegelhalter, et al., 2011), thereby presenting itself as a tool to dispel myths associated with regional spatiality. The research process is largely iterative and is derived from Mader & Eggnik's (2014) concept of CT (see Section 2.6). CT provides a foundation to answer the key questions of this research (see Section 1.4) by facilitating the scrutinisation of expert knowledge on mine closure and their opinion on the applicability of the Atlas. It provides a framework which allows for iterative modifications to the Atlas to be made.

Figure 5 illustrates how the concept of CT was adapted to the development of the Atlas. The development process was iterative as various phases illustrated in Figure 5 were revisited throughout the development process, allowing for extensive implementation of knowledge gained from stakeholder input.

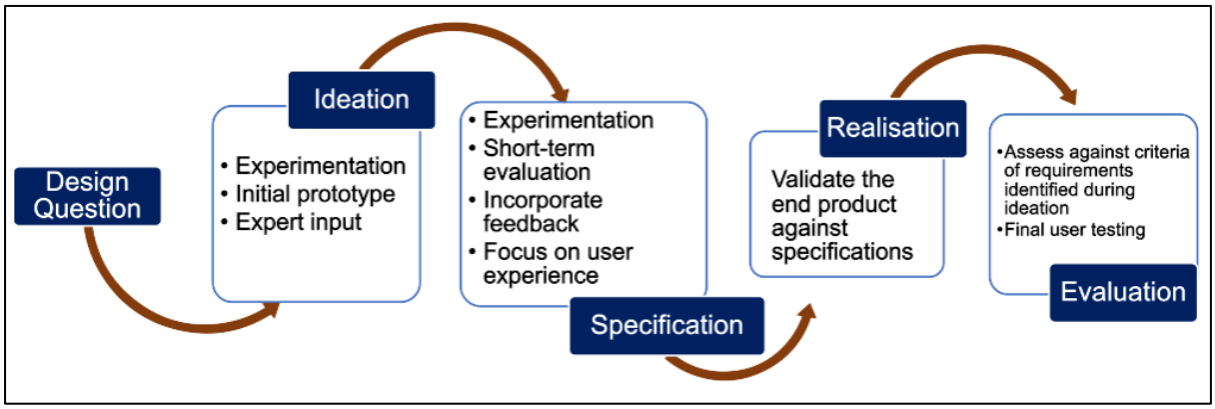

Figure 5: CT process applied to the development of the Atlas.

After numerous editions of the Atlas, the final version of the Atlas was produced. As a central database of information regarding mine closure, the Atlas can be used by all stakeholders associated with mine closure in South Africa. The benefit of the Atlas being freely available allows:

1. Stakeholders to access to data that would otherwise be scattered across various sources; and
2. A consistent basis of interpretation of data and information across all stakeholder groups allowing decisions regarding mine closure to be taken based on a single source of information as far as possible.

While adapting CT allows for the inclusion of numerous perspectives in the development of the Atlas, time constraints only allowed for a certain amount of engagement with stakeholders associated with mine closure and potential users of the Atlas. Should this research be conducted under more lenient

timelines and additional resources, more perspectives of the Atlas's usability and insights into the data that it contains can be incorporated in the research, providing for a more robust basis for development of the Atlas. This does, however, provide an opportunity for further development of the Atlas beyond this research project. While every effort was given to include as much data and information in the Atlas as possible, ideologies evolve over time and data and information gets updated. Therefore, the iteration of CT used to develop the Atlas, as discussed above, has the potential to be used to further develop the Atlas over time with new interpretation, ideas and data.

3.1. Adapting CT to the Development of the Atlas

Figure 6 summarises the process undertaken to develop the Atlas. The WRC Project Team identified the need for an online GIS tool to support decision making regarding mine closure risks and post-closure land use opportunities building on the work of Cole & Broadhurst (2020; 2021). Subsequent collection of open-source data then took place. Data was obtained from various different sources (full list of data used and their sources are summarised in Appendix A) and were organised into geospatial formats. The data collected for this study was not intended to be analysed, but rather to inform the development of the Atlas.

While some data was georeference, others were not. Consequently, all the data was converted into a consistent format and was georeferenced. The data was then used to develop the Beta 1.0 version of the Atlas (Figure 8), which was presented to the WRC Project Team's reference group to gauge expert opions on the need for an Atlas to support decision-making regarding mine closure risks and post-closure land use opportunities. Following positive constructive feedback from the WRC Project Team's reference group, the Beta 2.0 version of the Atlas (

Figure 9) was developed. Beta 2.0 was presented at an online multi-stakeholder engagement workshop conducted by the WRC Project Team. Stakeholders at the workshop were also given an opportunity to test the Atlas. Feedback from the stakeholders (Appendix B) who attended the workshop were used to develop the Beta 3.0 version of the Atlas (Figure **10**). Beta 3.0 was presented to a selected group who were given an opportunity to test the Atlas at a more granular level. A subsequent semi-structured interview with each interviewee was conducted and interviewees were asked to provide in-depth feedback on their experience and overall experience with their use of the Atlas. They were also asked to provide recommendations for further development of the Atlas, including recommendations of data that may be useful to be included in the Atlas. The concept of the Atlas was then presented at the Australian Centre for Geomechanics Mine Closure 2023 Conference in Reno, Nevada (United States of America) where it was scrutinised by international experts on mine closure. A final update was was applied to the Atlas to produce the final Mine Closure Risk and Opportunites Atlas for South Africa.

Stakeholder mapping and further details of quantitative and qualitative data collection and processing

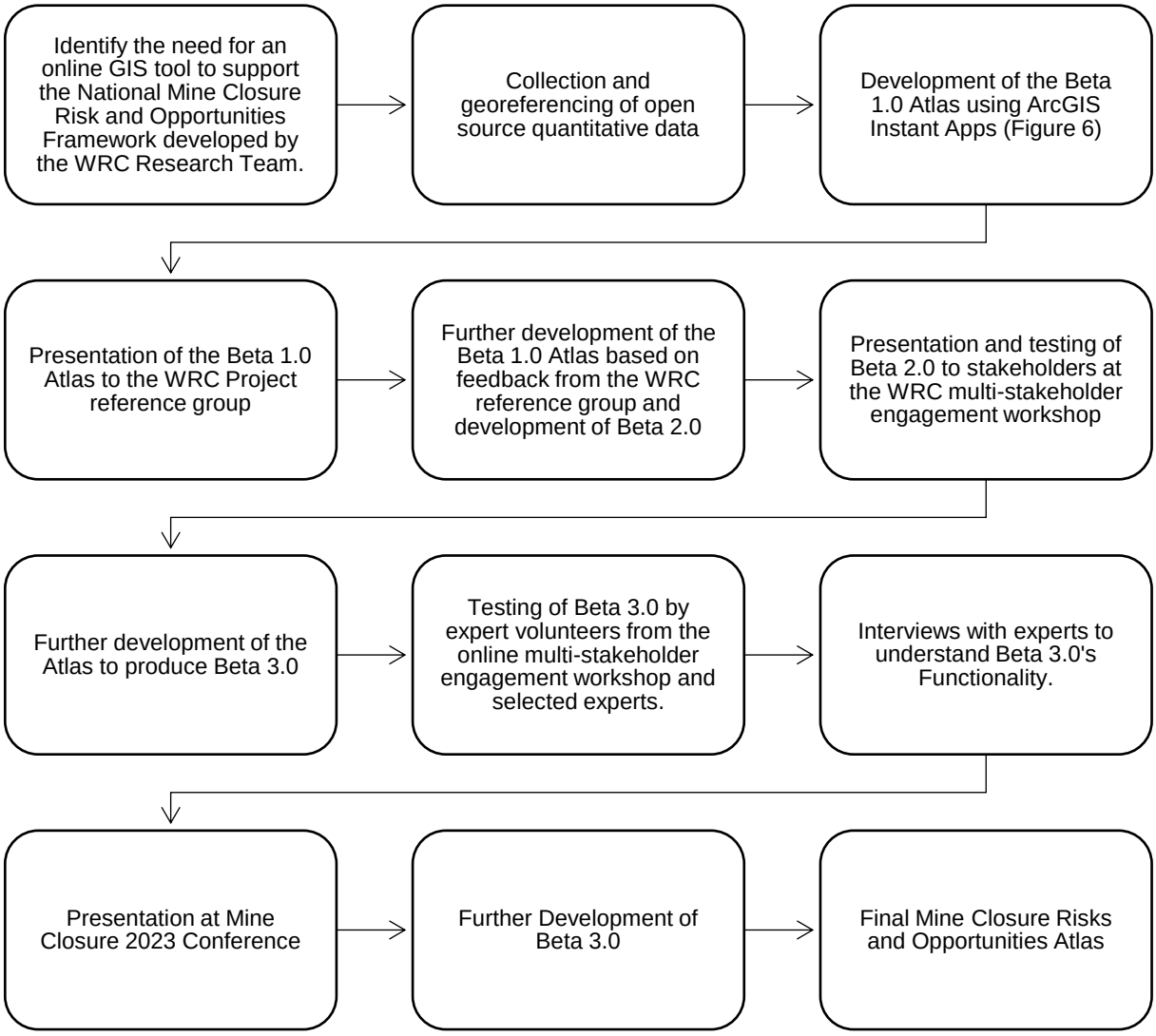

Figure 6: Development process undertaken to produce the final South African Mine Closure Risks and Opportunities Atlas

is discussed below.

3.2. Stakeholder Mapping

The Atlas was designed to be comprehendible by stakeholders with various backgrounds. Applying principles of the CT design process (Mader & Eggnik, 2014) and the general rules associated with co-development of software stipulated by Parenzo (2023) requires careful consideration of the intended users of the Atlas upon its launch. This would correlate with stakeholders associated with mine closure and mine closure planning. The ICMM (2019) identified the following key external stakeholders associated with mine closure and social transition planning processes: communities (within the mine's zone of influence); indigenous peoples/first nations/traditional land owners; workforce; government and regulators; industry peers; academia; media; and other sector contributors (including Non-governmental Organisations [NGOs]). Table 4 illustrates potential users of the Atlas by associating the key stakeholders of mine closure planning, as identified by the ICMM (2019), with the South African context.

The Atlas was designed to be comprehensible by stakeholders with various backgrounds. Co-development of software requires careful consideration of the intended users of the Atlas. Governmental organisations could use it for policy, planning and budgeting - knowledge of potential mine closure and impacts on local economy and communities will help them to identifying areas requiring intervention or monitoring. Mining companies could use the knowledge of potential risks and vulnerabilities of communities and environment for planning and budgeting. Consulting companies could use the Atlas for the assessment of risks and opportunities for mining companies and government. Investors could use it for making investment decisions on mining companies and on post-closure developments. The mining workforce could use the knowledge of potential mine closure and estimated timeframes for personal career planning. NGOs could use the knowledge of potential risks and vulnerabilities of communities and environment to raise awareness and engage with mining companies and local government. Mining host communities and labour sending areas could use it for planning and engagement. Table 4 illustrates potential users of the Atlas by adapting the key stakeholders of mine closure planning identified by the International Council on Mining and Metals (International Council on Mining & Metlals, 2019) to the South African context.

Table 4: Use of Atlas by different stakeholders in South Africa, adapted from the ICMM Integrated Good Practice Guide (2019)

Stakeholder group	Potential use of the Atlas	Scale of information	Frequency of use
National Government	Policy and planning	National	Annually
Provincial Government	Planning and budgeting	Regional	Annually
District Government	Planning and budgeting	Regional	Quarterly
Local Government	Planning and budgeting	Local	Quarterly
Mining Companies	Budgeting and planning	Local/regional	Annually
Consulting Companies	Risk assessments and post-closure land use opportunities assessments	Local/regional	Daily
Investors	Investment decisions on mining and post closure developments	Regional/local	Monthly
NGOs	Raising awareness and engagement	Local	Monthly
Mining communities	Planning and engagement	Local	Ad hoc
Labour Sending Areas	Personal planning and engagement	Regional/local	Ad hoc
Traditional Authorities	Raising awareness and planning	Local	Ad hoc
Mine workforce	Career planning and employer engagement	Regional/local	Ad hoc
Labour unions	Engagement and negotiations with mine employers	Local	Ad hoc
Researchers	Conduct research that informs mine closure policy and planning	National/regional/local	Ad hoc
Media	Raising awareness	National/regional/local	Ad hoc

3.3. Data Collection and Processing

3.3.1. Quantitative Data Collection

Publicly available socio-economic and environmental data was collected from various sources by the WRC Research Team. Data pertaining to socio-economic conditions (e.g., access to piped water) of South African mining host communities was collected by Cole & Broadhurst (2020) from StatsSA census. Cole & Broadhurst (2020) also classified each mining host community as either small mining towns, pre-existing towns, pre-existing communities, co-established cities or large mining towns. The WRC Project Team mapped (using their existing knowledge on mines in the country and prior research) and classified all large-scale mines in South Africa by type of commodity mined and the environmental, likelihood of closure and socio-economic risk rating given to them by the team.

Environmental data pertaining to South Africa (e.g., land capability and protected areas) was collected from a variety of sources such as SANBI, the BirdLife International Programme and the South African DFFE. A full list of data sources is provided in Appendix A. Table 5 summarises the criteria used for data collection and the applicability thereof.

Table 5: Criteria and applicability of data selection

Criteria	Applicability
Legislative baring	The dataset is prescribed to be included in assessments of mine closure or environmental planning (either through consideration in EIA processes [and associated specialist discipline studies] promulgated in terms of the National Environmental Management Act 107 of 1998, the MPRDA or other applicable legislation).
Availability	The dataset is open-source and available for public use, negating the requirement for any financial implications for the use of the Atlas.
Reliability	Only reputable datasets were used. The datasets were either provided by government organisations (e.g. the DFFE) or by reputable research organisations / projects (e.g. the Global Energy Monitor, the Global Tailings Portal and SANBI). The datasets must be as complete as possible. Incomplete datasets were avoided as far as possible, however where the incomplete dataset was the only available dataset, this was used.
Format	Data must have the potential to be georeferenced and graphically represented.

3.3.2. Quantitative Data Processing

Quantitative data was georeferenced[7] if it was not already. It was then converted into GIS compatible formats such as Shapefiles and Keyhole Markup Language (KML) file types using ArcGIS Pro 2.9.5 and QGIS Desktop 3.22.3. The World Geodetic System 1984 (WGS84) datum projection was used for all the data. The quantitative data was then uploaded to ArcGIS Online – a web-based mapping software

[7] The internal coordinate system of the data was related to the ground system of geographic coordinates (Uited States Geological Survey, 2023).

developed by Esri. The data was then compiled into an ArcGIS web map (Esri, 2023) (Figure 7). An ArcGIS web map is a display of geographic information that can be interacted with (Esri, 2023).

The web map was then inserted onto a user interface. Multiple iterations of the user interface were developed using ArcGIS Instant Apps and ArcGIS Experience Builder. ArcGIS Instant Apps provide templates for developers to display georeferenced information (Esri, 2023). The first iteration of the Atlas was developed using ArcGIS Instant Apps (Figure 8). ArcGIS Instant Apps is a template-based mapping platform that allows users to create simple interactive maps based on existing templates. While the simplicity of ArcGIS Instant Apps is convenient, it did not provide an extensive enough analytical framework required for the level of analyses intended to be facilitated by the Atlas. ArcGIS Experience Builder is a more flexible solution for developing web map applications such as the Atlas. ArcGIS Experience builder is a platform that enables developers to create highly configurable web applications without requiring knowledge of computer programming/coding (Esri, 2023). ArcGIS Experience Builder allows developers to embed web maps in a customisable layout . Users can also choose and configure numerous widgets that interact with the web map (e.g., a widget can be added for users to add their own data to the web map). ArcGIS Experience Builder can be configured to work on desktops/laptops, tablets, and smartphones. The second Beta version (Beta 2.0) (Figure 9), the third Beta version (Beta 3.0), (Figure 10) and the final version of the Atlas was developed using ArcGIS Experience Builder (Figure 12).

The Beta 2.0 version presented an example of the possibilities offered by ArcGIS Experience Builder. However, no widgets were configured with for Beta 2.0 as the researcher did not possess the skills to do so at the time of its inception. Widgets were first introduced in the Beta 3.0 version and presented possibilities for analytical operations. The widgets were fine-tuned and correctly configured for the final version of the Atlas (see Table 6 for more information about the widgets used in the Atlas).

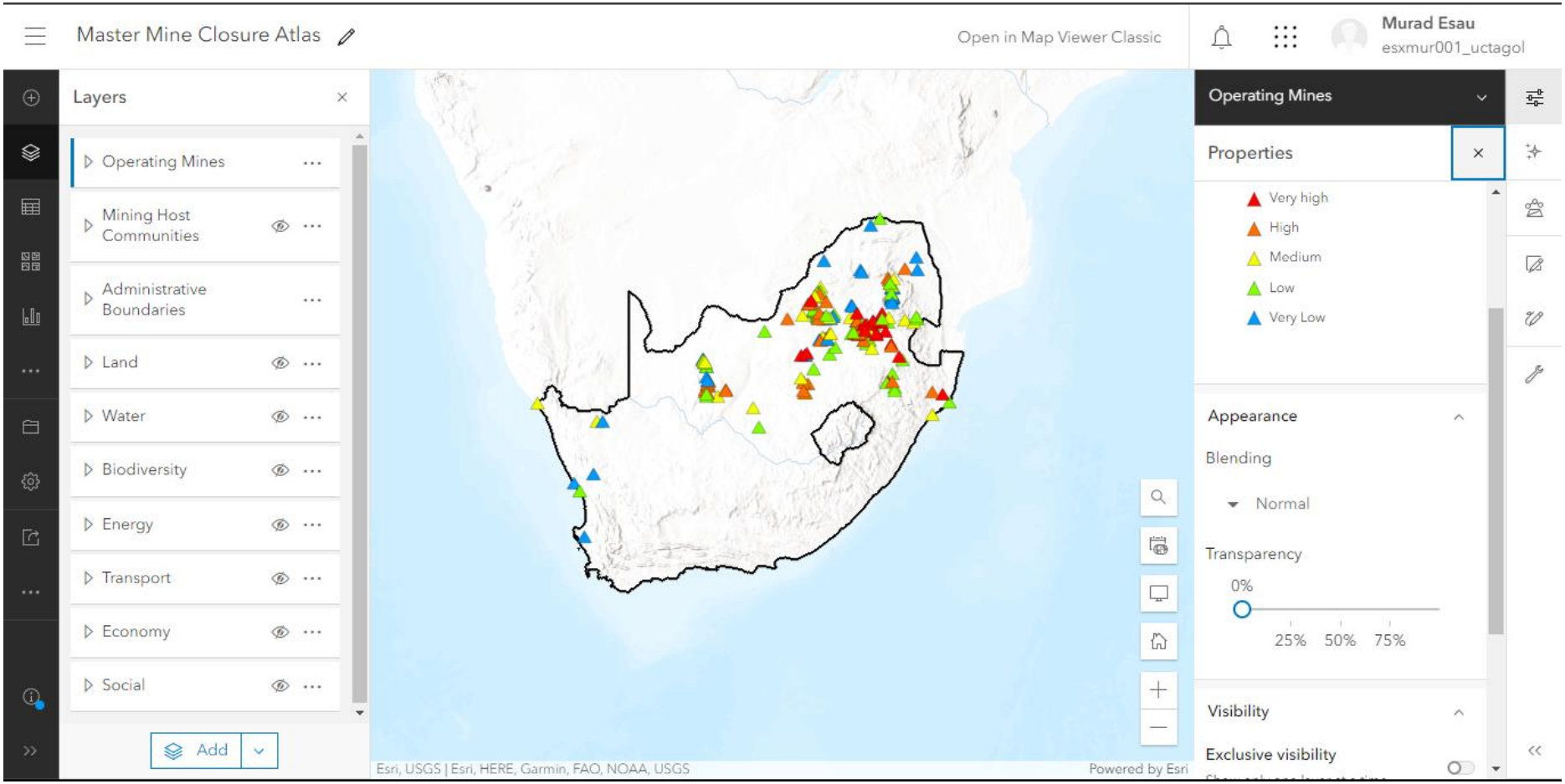

Figure 7: ArcGIS Web Map that was embedded into user interfaces

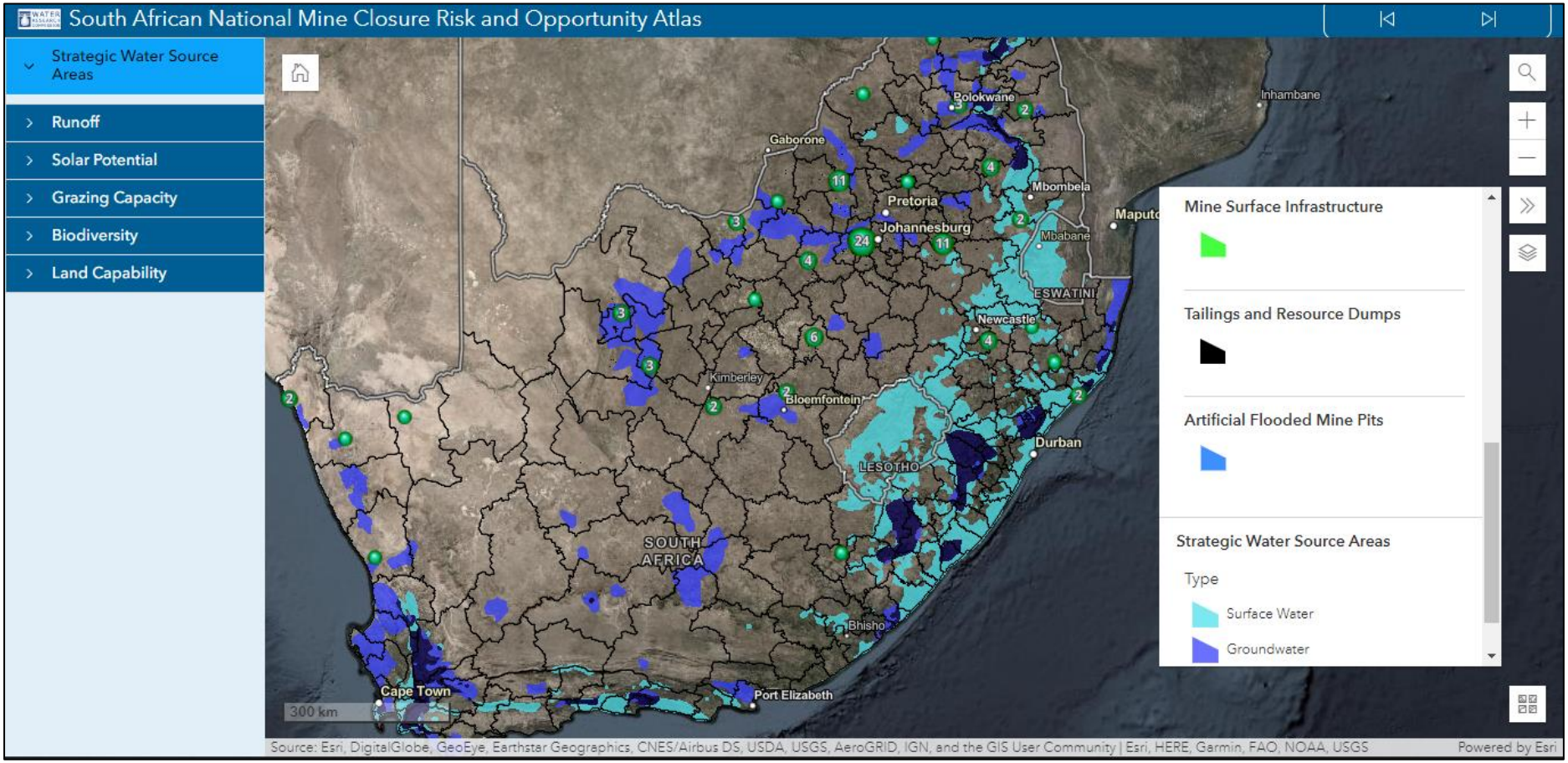

Figure 8: Beta 1.0 version of the Atlas developed using ArcGIS Instant Apps 'Exhibit' template.

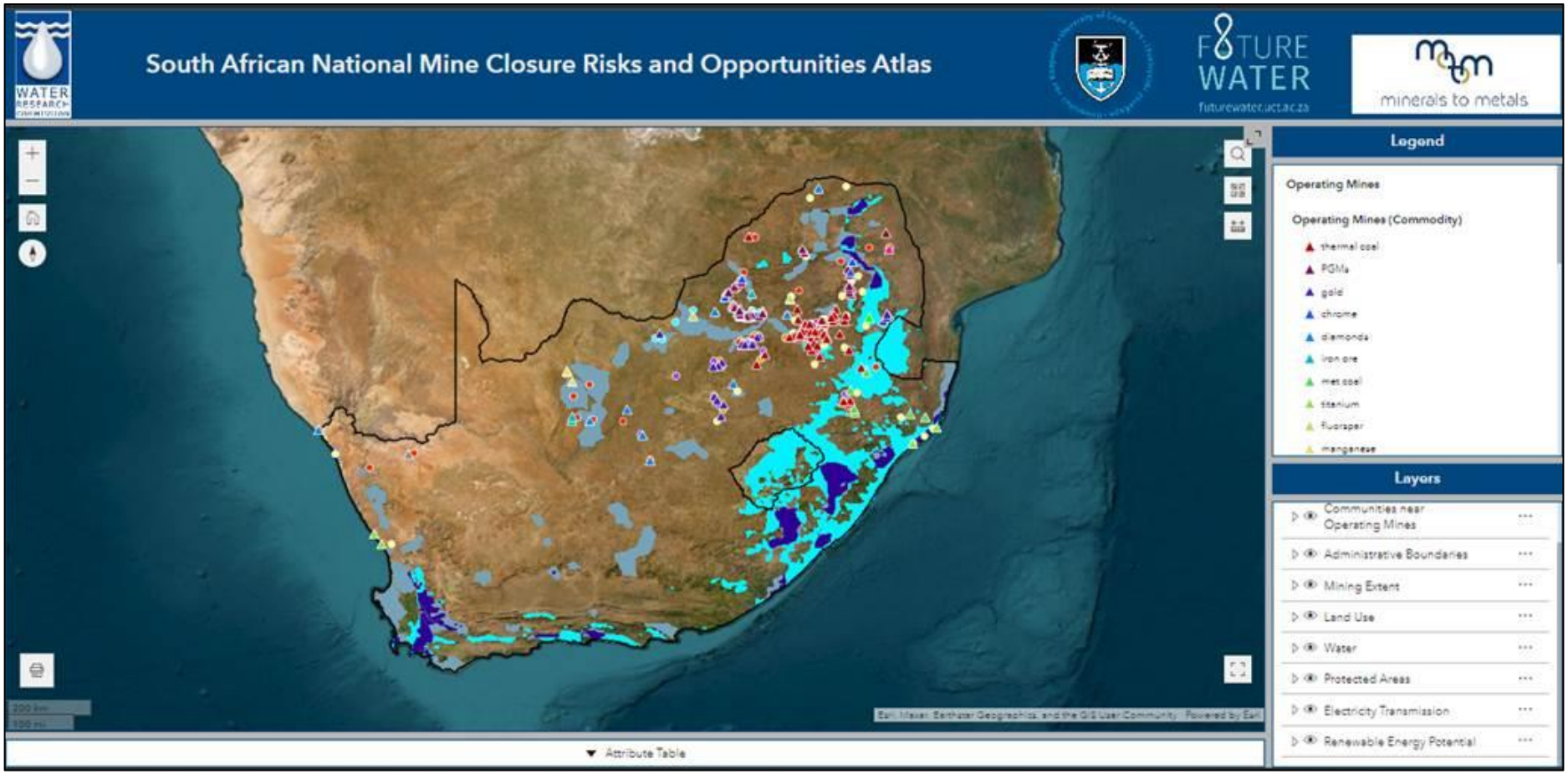

Figure 9: Beta 2.0 version of the Atlas developed using ArcGIS Experience Builder

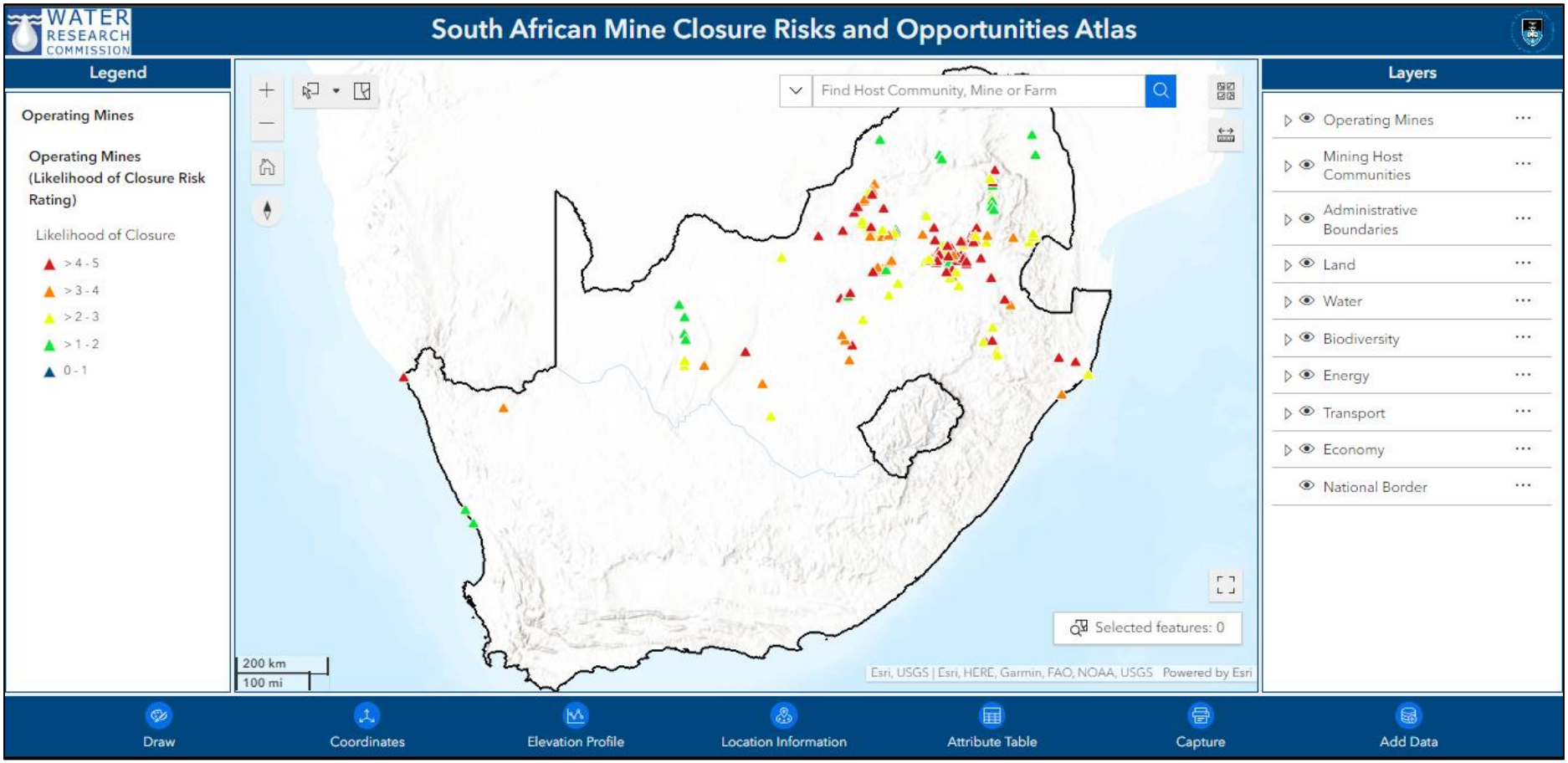

Figure 10: Beta 3.0 version of the Atlas developed using ArcGIS Experience Builder

3.3.3. Qualitative Data Collection

A prototype of the Atlas (Beta 1.0) was developed and presented to an audience consisting of experts who were part of the WRC Research Team reference group. After the presentation, the reference group was given an opportunity to verbally provide feedback to the researcher. The Atlas was further developed based on this feedback and presented at a multi-stakeholder engagement workshop where further feedback on the Atlas was provided, this time subject to users testing the Atlas for themselves (see Section 3.3.4 for more detail). The Atlas was further developed based on this feedback and underwent a process of specialised user testing with relevant stakeholders and experts. Specific users were asked to test the Atlas and provide feedback on their experience using it (see Section 3.5). The Atlas was, once again, updated and presented at the Mine Closure 2023 Conference (hereinafter referred to as 'the Conference') where international industry experts provided input on the concept of the Atlas by means of a Question and Answer session after it was presented.

The Atlas was finalised with consideration given to inputs from the all the experts and stakeholders as well as the researcher's own knowledge of GIS. Careful consideration was also made to avoid placing biased information in the Atlas. Three case study areas were then assessed for (hypothetical) mine closure risks and post-closure land use opportunities using the Atlas. The following sections provide details of the engagement with participants.

3.3.4. Atlas Presentations

The WRC research team presented the risk rating framework and the Beta version of the Atlas to the WRC reference group on via Microsoft Teams. The Beta 1.0 version was developed using ArcGIS Instant Apps. It had a user interface as shown in Figure 8. It was stressed in the presentation that it was a Beta version of the Atlas and was in very early stages of development. The Atlas was presented before the reference group were offered an opportunity to provide their opinion on the Atlas, albeit in its initial phase. The concept of data integration was the main focus of this presentation, with little analytical capabilities available at this stage. The Atlas was updated with the feedback of the reference group to develop Beta 2.0 version of the Atlas using ArcGIS Experience Builder (Figure 9).

The online multi-stakeholder engagement workshop was hosted on the 6th of March 2023 via Zoom. Over 30 people from academia, consulting, government, civil society and industry experts were invited to participate in the workshop. 15 people attended and participated in the workshop, with nine people staying until the end of the two-and-a-half-hour-long workshop. The WRC Research Team presented the initial stages of the development of a mine closure risk framework for measuring social and environmental risks and opportunities related to mine closure for all large-scale mines and their host communities in South Africa. The Beta 2.0 version of the Atlas (Figure 9) was then presented. The Atlas's functionality (including how to turn layers of data on and off and the breadth of information contained in the Atlas) was presented to the workshop participants before a live link to the Atlas was shared with them. Participants were given ~15 minutes to use the Atlas and were encouraged to explore mining regions that they are familiar with using the Atlas and the data contained within it. They were also encouraged to ask questions and comment on the Atlas while using it. Participants were then asked

to complete a survey using Zoom's Advanced Poll functionality. Survey questions were divided into five themes – layout and experience; information; visualisation; distribution; and further resources. Each theme comprised of one to two questions. A total of eight questions were asked in the survey (see Appendix B for the full list of questions and a summary of responses provided by participants).

The concept of the Atlas was presented at the Australian Centre for Geomechanics Mine Closure 2023 Conference. The Conference was attended by delegates from across the world who are interested and involved in mine closure. These delegates included academics, consultants, mine closure experts and representatives of auxiliary industries involved in mine closure. Since the Atlas was not made publicly available at the time of the Conference, its concept and development methodology were presented instead by means of (mainly) screenshots and fragments of information presented in a Microsoft PowerPoint presentation. This included a description of the Atlas' design, examples of its functionality and the challenges and opportunities associated with it. After the presentation, delegates were given an opportunity to ask questions and comment on it. Afterburner one-on-one conversations with delegates were held after the main presentation took place.

3.4. Case Studies

The WRC research project observes four case study areas to explore the challenges of mine closure and opportunities for post-closure land use development in three regions in South Africa – West Wits, eMalahleni and Mogalakwena. One mine that is part of each of the WRC project's case study regions (three in total) were considered in this study for the purpose of testing the process of using the Atlas. The Atlas, through observations and analyses of the datasets contained within it, was used to assess potential risks of mine closure and potential post-closure land use developments for the three mine sites.

The mines were strategically selected so that the Atlas is applied to mines with a variety of characteristics. Mines with varying life spans (Life of Mine [LoM]), commodities mined, numbers of employees and in various geographic locations in South Africa were selected for assessment. Criteria used to select the mines include the number of employees (permanent and contractors) of the mine, LoM, type of commodity mined and geographic location of each mine. After applying this criterion to the case study areas observed in the WRC project, the following mines were selected as case studies for testing the Atlas: Kusasalethu, Matla and Mogalakwena. The selection criteria for each mine are shown in Table 7.

3.5. Expert Interviews

Targeted interviews were undertaken to gauge the opinions of individuals who are expected to be users of the Atlas. The aim of the interviews was to understand the opinions of potential users of the Atlas, drawing on their knowledge of the field of mine closure and GIS applications. A summary of interviewee responses is provided in Appendix D.

3.5.1. Participant Selection

Interviewees were selected based on their knowledge of various aspects of the mining industry and guided by the key stakeholders of mine closure planning identified by the ICMM Good Practice Guide for Mine Closure (International Council on Mining & Metlals, 2019). Convenience sampling of participants who volunteered for further involvement in the development of the Atlas at the online multi-stakeholder engagement workshop was used. Additional participants were selected based on their specialisation in the mining, academic, government, and consulting sectors. A total of five interviews of experts in the relevant sectors were conducted.

3.5.2. Testing

An overview of the Atlas and its purpose was explained to participants prior to their testing. The Atlas's concept, envisioned purpose, and functionality was explained to participants. They were then given one hour to use the Atlas and were asked to explore the various tools and datasets contained within the Atlas. Participants were encouraged to do this in relation to a mine and/or mining community that they are familiar with and to possibly generate a map of their chosen mining area or community using the Atlas.

3.5.3. Interview Questions

A set of 12 questions were used to guide the semi-structured interviews with experts and stakeholders involved with mine closure (Appendix C). The guiding questions expanded on those posed in the survey for the multi-stakeholder engagement workshop and included additional discussions with each interviewee. As with the multi-stakeholder engagement workshop, the guiding questions were divided into six themes: 1) Layout and Experience; 2) Information; 3) Visualisation; 4) Distribution; 5) Further Resources; and 6) General Comments.

CHAPTER 4

4. Results

This chapter outlines the results of the development process undertaken to produce the Atlas. A description of the final Atlas (Section 4.1) is given followed by feedback given by experts and stakeholders during the three presentations (Section 4.2). A description of the researcher's experience using the Atlas to produce maps of the Case Study areas is then given (Section 4.3) followed by feedback from the participants of the testing interviews phase (Section 4.4).

4.1. Atlas

The following link provides access to the Atlas - South African Mine Closure Risk and Opportunities Atlas.

The Atlas displays data pertaining to all operating mines in South Africa, South African mining host communities, host local municipalities and datasets related to mining, mine communities and post-closure development planning. When opening the Atlas, users are greeted by a splash page which provides a brief description of the Atlas, the data it contains, and its intended purpose (Figure 11). The default map then appears (after closing the splash page) displaying all large-scale operating mines in South Africa on a white basemap of South Africa (Figure 12). A Layers panel on the right provides access to all the datasets which are categorised under ten headings/themes – Operating Mines, Mining Host Communities, Administrative Boundaries, Land, Water, Biodiversity, Energy, Transport, Economy and Social. Each categorised heading has a dropdown menu of all the relevant datasets which can be displayed on the main map by toggling on or off as required. A 'Details' page, which opens in a new tab in a user's browser and provides a brief overview of the dataset and a direct link to its source, is linked to each dataset. A Legend is included in the Layers panel under each them and shows the legends for the current active layers. The Legend automatically updates according to the layers toggled on or off.

Selecting a mining host community or mine of interest from the map prompts a pop-up which presents discrete data pertaining to the selected feature (mine or mining host community) to be displayed (Figure 13). Built-in interactive tools allow users to search for a particular location on the map by typing in key words or the location's name, zoom in or out, toggle spatial layers on or off, and change the base map. Widgets have been added to the Atlas (located on the left hand side of the Atlas) to enable users to draw graphics, add their own data, plot elevation (Figure 14), and capture and download static maps (such as those presented in section 3.4). A full list of widgets included in the Atlas and their respective functionality is presented in Table 6. While the Atlas works best on a desktop or laptop, it has also been calibrated to work on smartphones and tablets (Figure 15). It can be accessed through a browser on the respective device. When using the Atlas on a tablet or smartphone, navigation is not as sophisticated as when used on a desktop or laptop. Some functions may not work, however the datasets contained in the Atlas is consistent across all devices.

Table 6: Widgets contained in the Atlas and their function.

Widget	Function
Web Map	The web map containing all the relevant data. Users can select features on the map to display more information about them by clicking (laptop/desktop) or tapping (tablet or smartphone) on them. The web map contains an orientation button, default view button (zooms to a default view of South Africa), zoom in/out buttons, basemap button (allows users to choose between various types of basemaps), search button, measure button (allows users to measure distances and areas on the web map), and a full screen button.
Legend Panel	Defines features displayed on the web map
Layers Panel	A list of all the data contained within the web map. Data is grouped according to themes associated with mine closure risks and post-closure development. Groups can be expanded using the 'expand' arrow on the left of each group. Layers can be hidden or unhidden using the 'eye' icon next to the 'expand' icon. Three horizontal dots on the right of each layer allows users to increase or decrease the transparency of the particular layer. It also provides users with a link to a 'Details' page where more information about the selected layer is given, in addition to a link to the source of the data.
Draw	Allows users to create simple graphics for points, lines, and polygons on the web map.
Elevation Profile	Generates and displays an elevation profile based on a path created by drawing lines on the web map. Slope and elevation statistics can also be viewed.
Attribute Table	Displays the database used to create the web map in tabular format. Layers to be displayed can be selected from the drop-down menu. Features can be selected and filtered according to user preference using the 'show/hide' icon. The attribute tables can also be downloaded in csv. format.
Print	Allows users to create static maps of the map extent displayed in the web map when the capture widget is selected. A legend, north arrow, and scale bar can optionally be added to the map by configuring the 'advanced' options.
Add Data	Add data sources to the Atlas at run time. Data can be added via ArcGIS content, URL, or local storage (shapefile, csv., or GeoJSON formats)[8].
Location	Allows users to find and analyse features within a specified distance of a selected location[9].
Coordinates	Displays coordinate values on the map.

[8] csv files are restricted to 1 000 records and all other file types are restricted to 4 000 records. The maximum file size for shapefiles is 2 mb and is 10 mb for all other file types.

[9] The location widget is limited to utilising 10 datasets contained in the Atlas due to server constraints. The data included in the Location widget was selected based on the researcher's perception of the kind of data that is useful at a local or regional scale, which are the scales at which this tool will predominantly be used for.

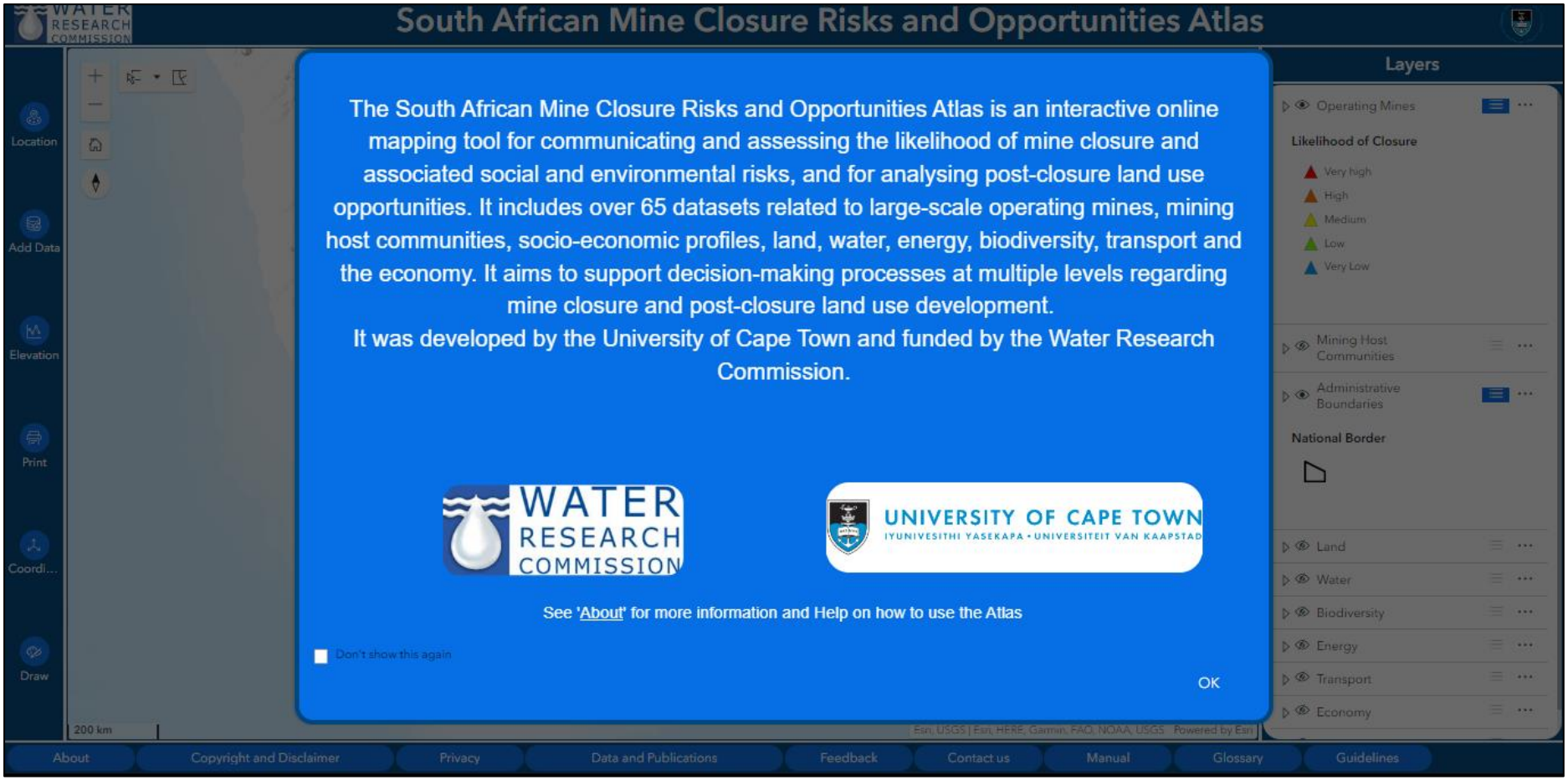

Figure 11: Splash page of the Atlas

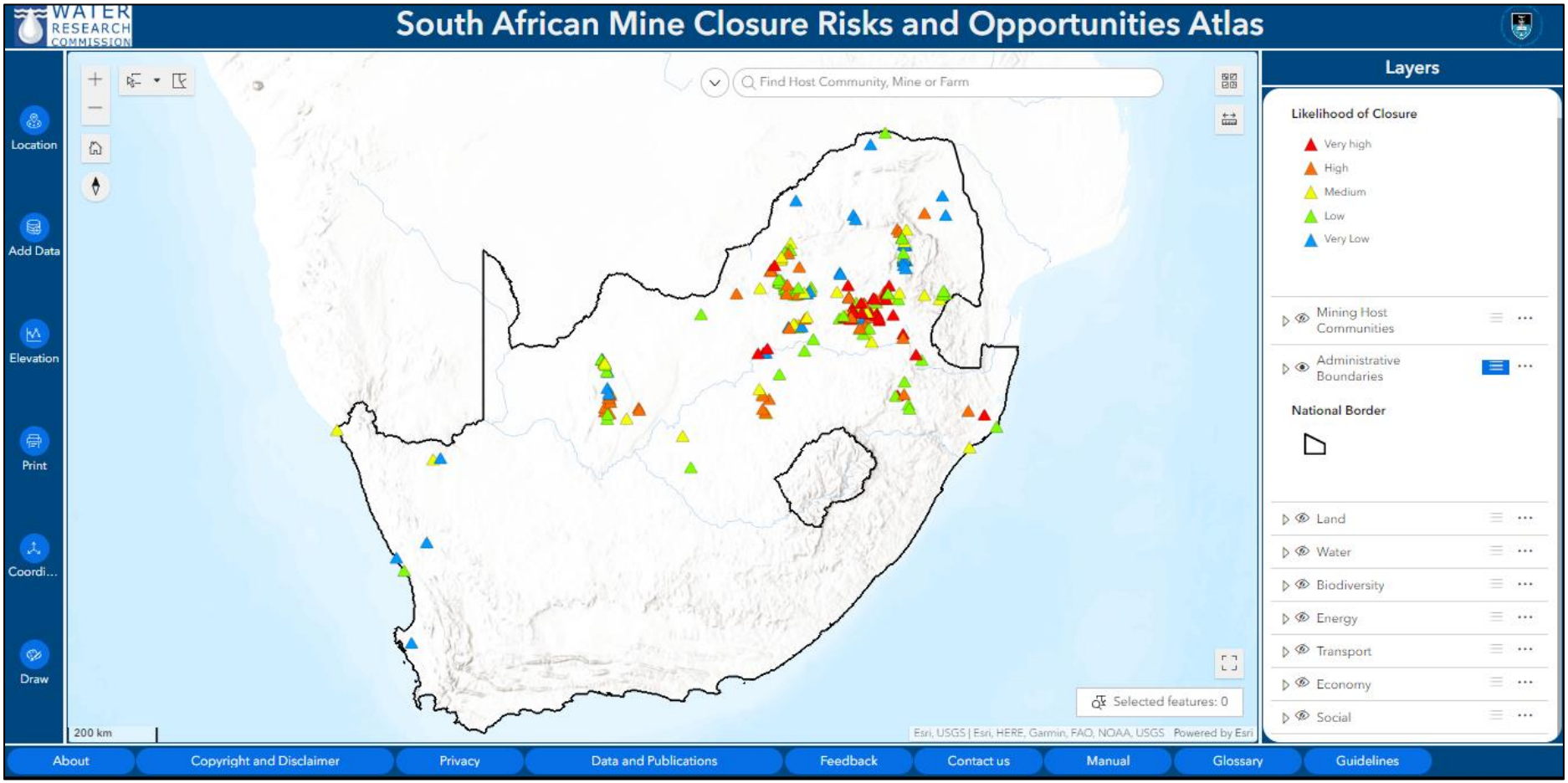

Figure 12: Default Atlas map showing all operating mines and mining host communities in South Africa.

Figure 13: Discrete data pertaining to the mining host community of Lutzville presented in a pop-up.

Figure 14: Elevation profile between the Tormin Titanium mine and Lutzville mining host community

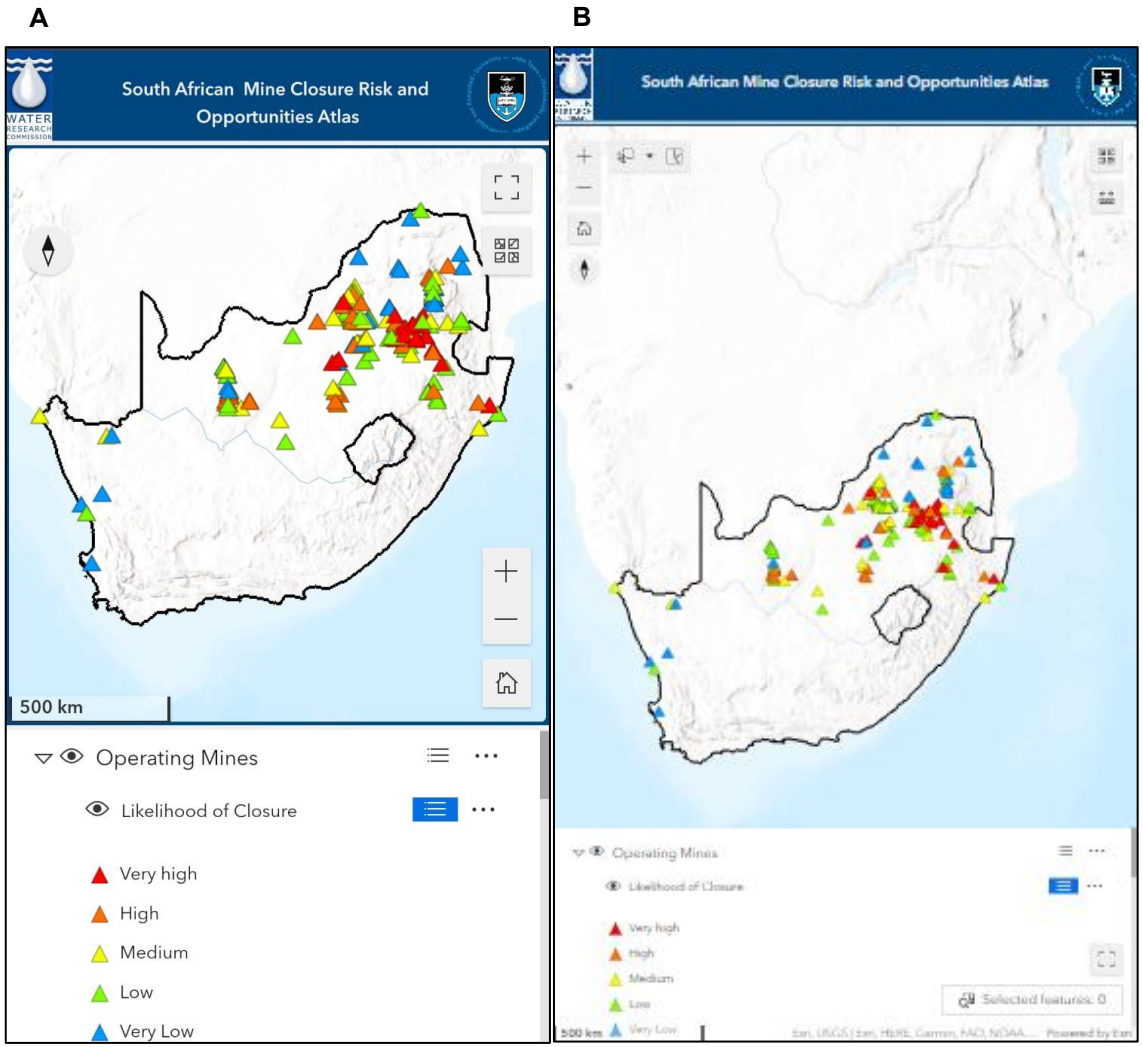

Figure 15: The Atlas view on a smartphone (A) and Tablet (B)

4.2. Presentations

4.2.1. WRC Project Team Reference Group

The WRC Research Team's reference group voiced their support for the development of the Atlas upon its presentation to them, albeit in its infancy phase. The main driver behind the group's support was the fact that there is currently no database such as the Atlas that is available to the public. The reference group also provided feedback on the layout of the Atlas, particularly focussing on the visual representation of features. Some members of the reference group stated that they were colour blind and could not differentiate between some map features – specifically the various shades of blue representing different datasets related to water. The reference groups also advised that the Atlas should contain a dataset that presents the clusters of mines in South Africa and the likelihood of mine closure at the scale of each cluster.

4.2.2. Online Multi-stakeholder Engagement Workshop

Based on the responses to the questions posed to the audience at the online multi-stakeholder engagement workshop (Appendix B), it can be assumed that the audience was satisfied with the overall layout and functionality of the Atlas. No issues were raised regarding the format of the visualisations or the tools available for use within the Atlas. However, issues related to the information hosted in the Atlas were raised. In broad terms, these issues mainly pertain to the lack of local scale information regarding mine closure. However, it was noted that this information may be difficult to obtain (from the DMRE and mining companies). Furthermore, the audience emphasised that more expert input is needed to fully develop the Atlas and incorporate sufficient information. Participants were advised that individual interviews were planned to be conducted with relevant experts in a subsequent phase of development of the Atlas (audience members from the workshop were also invited to take part in these interviews) (see Section 4.4). Lastly, the audience provided valuable information regarding the distribution of the Atlas and further resources that will be of use for its further development. A summarised table of responses is presented in Appendix B.

4.2.3. Presentation at Mine Closure 2023

During the questions and answer session after the presentation at the Conference, questions were asked about the development of the risk rating system used estimate the likelihood of mine closure, environmental risk of mine closure and the social risk of mine closure. The individuals who asked these questions were referred to the WRC Research Team, who is developing this risk rating system. Questions were also asked about the potential use of Artificial Intelligence (AI) in the use and development of the Atlas. While AI is an interesting avenue to pursue, it must be noted that the intention of the Atlas is not to provide answers and direction with regards to mine closure risk assessment and post-closure development – something that AI aims to pursue. Rather, the Atlas is meant to facilitate interpretation by its users. Questions about the use of the Atlas by industry was also asked, and whether the mining industry would use the Atlas to make decisions about mine closure and post-closure development. Again, it was responded to with the fact that the Atlas merely facilitates decision making rather than providing answers. Additionally, it was noted that the Atlas is intended to be used by all

stakeholders, including mining companies. However, care must be taken not to make the incorrect assumptions based on data contained in the Atlas.

4.3. Case Studies

Based on the criteria for the selection of mines as case studies (Section 3.4), the Kusasalethu gold mine in the West Rand Local Municipality (LM) in Gauteng, Matla coal mine in eMalahleni LM in Mpumalanga, and Mogalakwena PGM mine in the Mogalakwena LM were selected (see Figure 16 for the locations of the mines). Table 7 summarises the details of the criterion for each mine. A series of maps produced in the regions of each mine using the Atlas is presented below (Figure 17 to Figure 25). Each map displays all operating mines, mining communities and mine site features, together with different datasets related to environmental risk, likelihood of closure, social risk and post-closure land use opportunities.

Table 7: Mines used as case studies, the number of employees working at them (permanent and contract), their LoM, and Geographic Regions and Coordinates

Mine/Colliery	Local Municipality	Coordinates (decimal degrees)		Employees	LoM in 2022 (years)	Commodity
		Latitude	Longitude			
Kusasalethu	West Rand	-26.45388889	27.35916667	4260	2	Gold
Matla	eMalahleni	-26.26345	29.12681	2501	46	Coal
Mogalakwena	Mogalakwena	-23.992326	28.904495	7474	76	Platinum Group Metals (PGMs)

Figure 17, Figure 18 and Figure 19 illustrate the DFFE Mining and Biodiversity Guidelines; grazing capacity; and Protected and National Protected Areas Expansion Strategy (NPAES) areas and SWSA, respectively, in the area around the Kusasalethu gold mine. Figure 20, Figure 21 and Figure 22 illustrate Economic Production for Mining and Quarrying, Land Capability, and Wind Speed (at 100m altitude), respectively, in the area around the Matla coal mine. Figure 23, Figure 24, Figure 25 and illustrate the Direct Normal Irradiation, Mean Annual Runoff, and Water Courses, respectively, in the area around the Mogalakwena PGM mine.

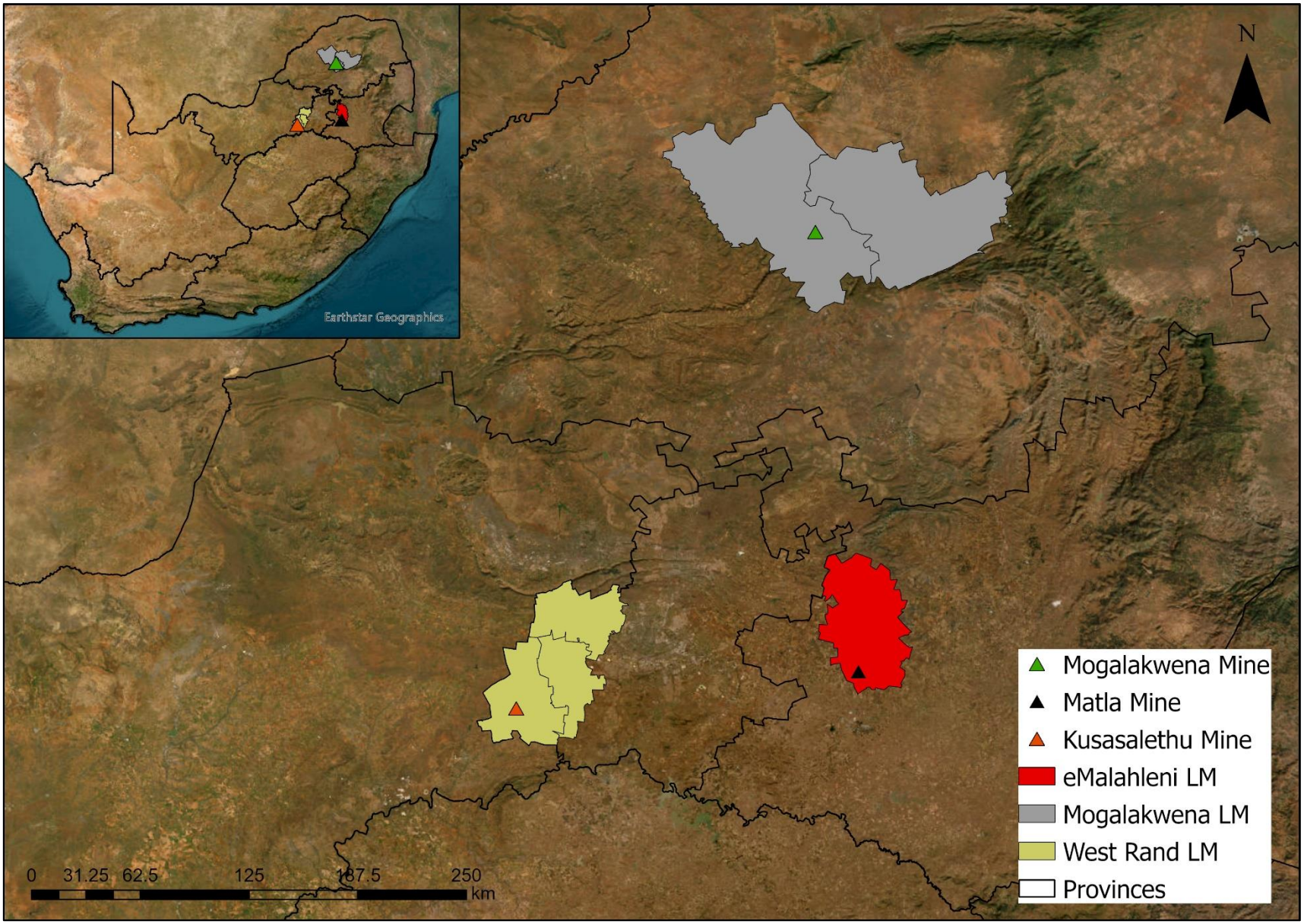

Figure 16: Regions and Locations of the Case Study Mines

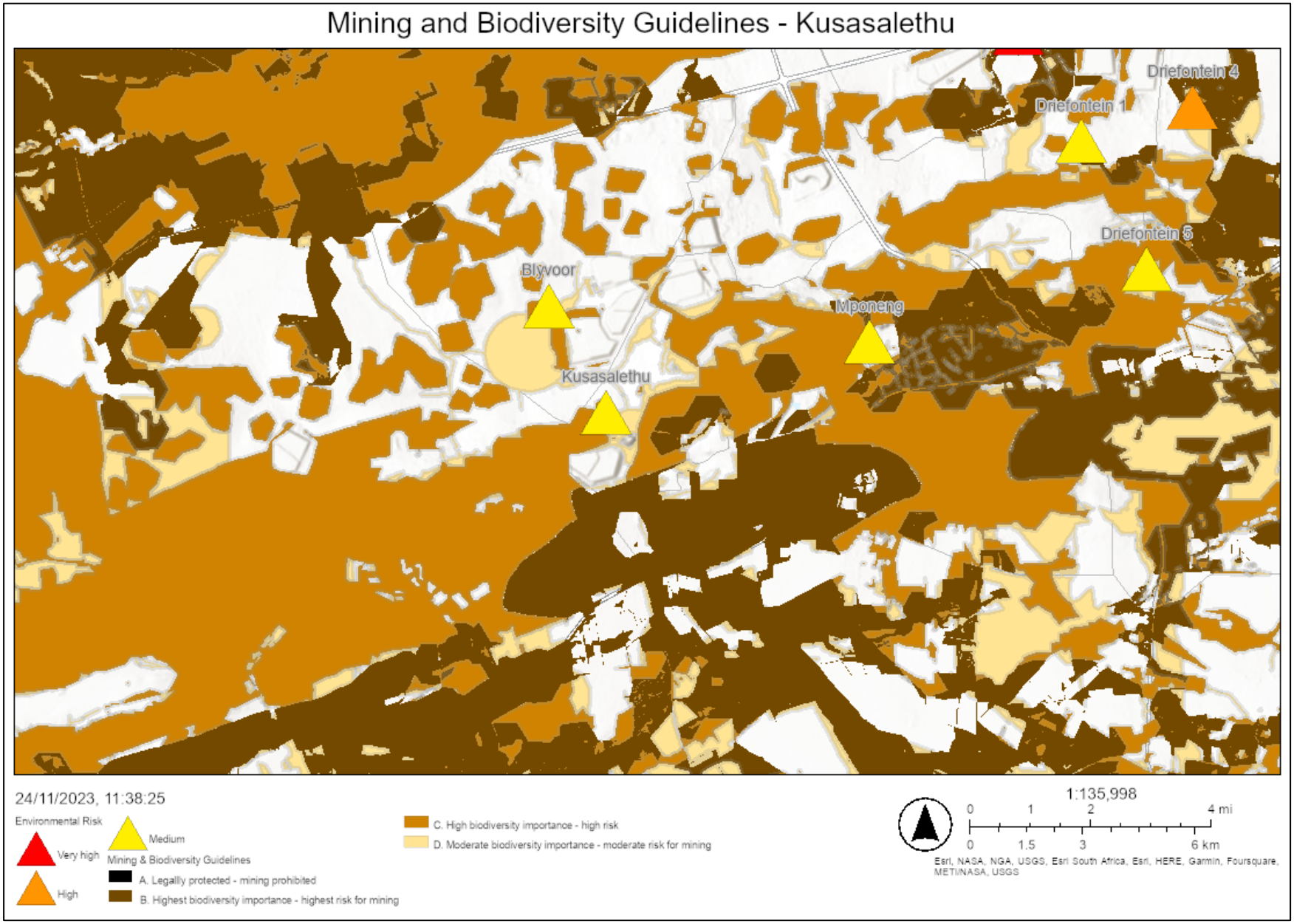

Figure 17: Mining and Biodiversity Guidelines around the Kusasalethu Mine

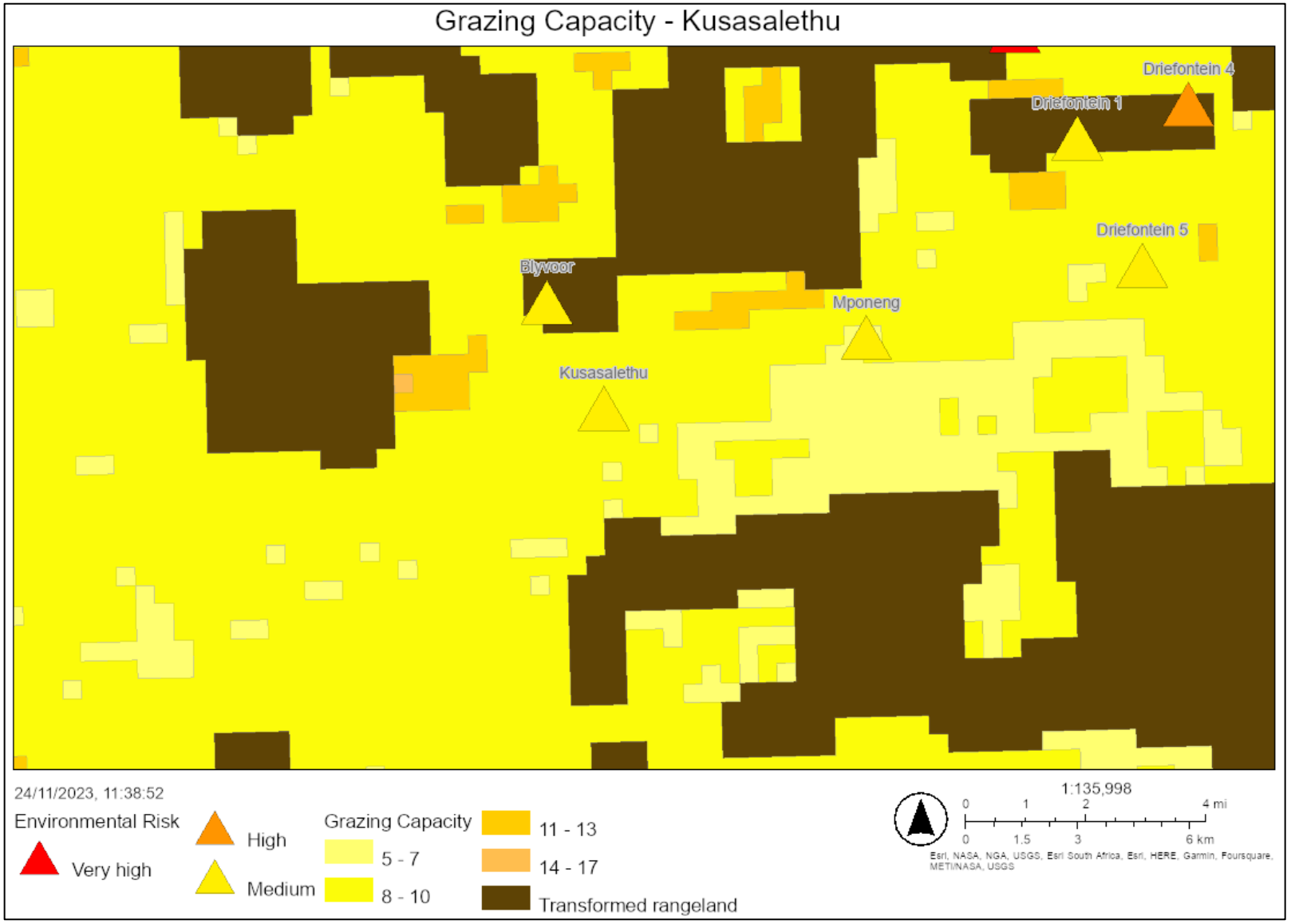

Figure 18: Grazing Capacity around the Kusasalethu Mine

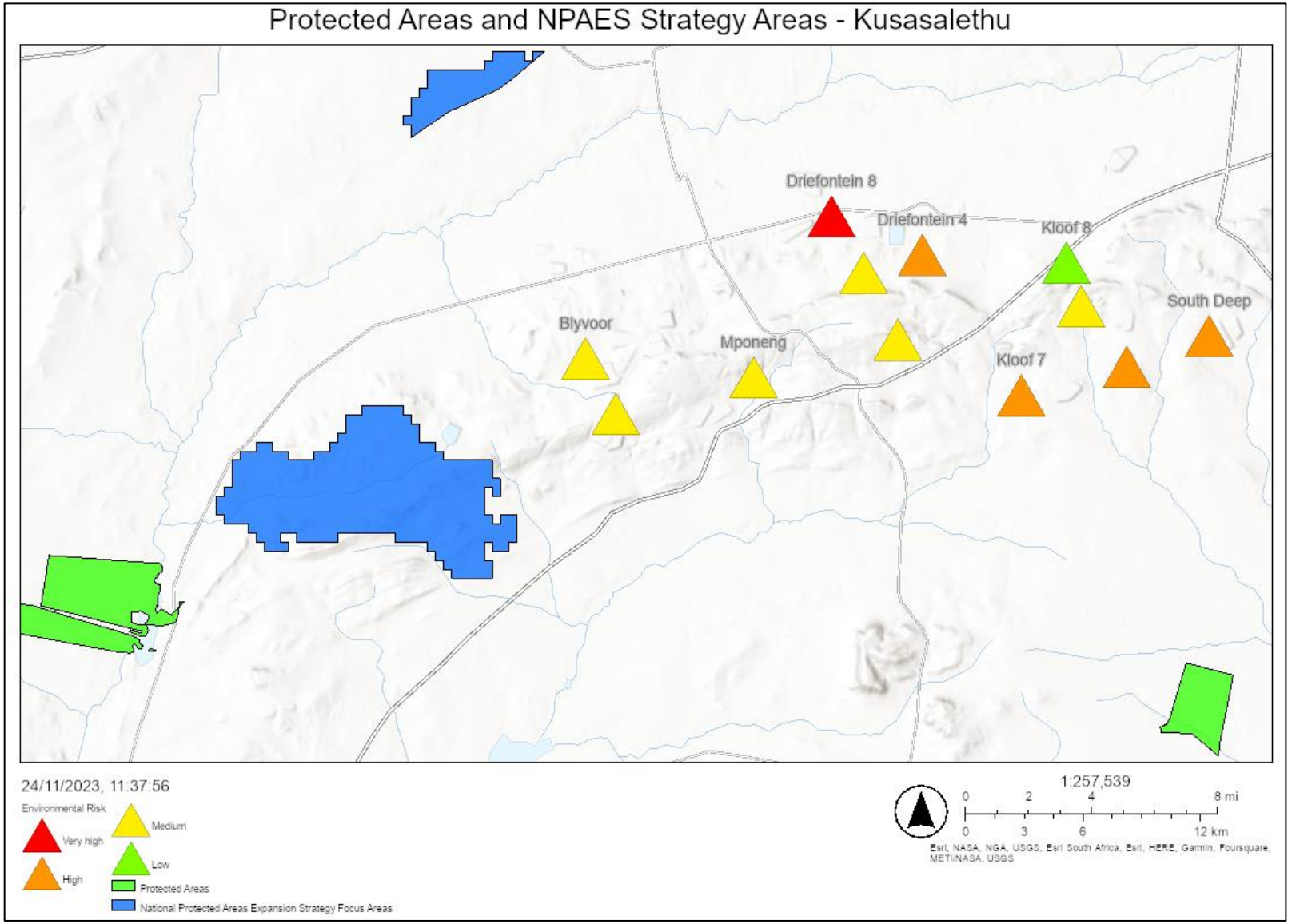

Figure 19: Protected and National Protected Areas Expansion Strategy Focus Areas around the Kusasalethu Mine

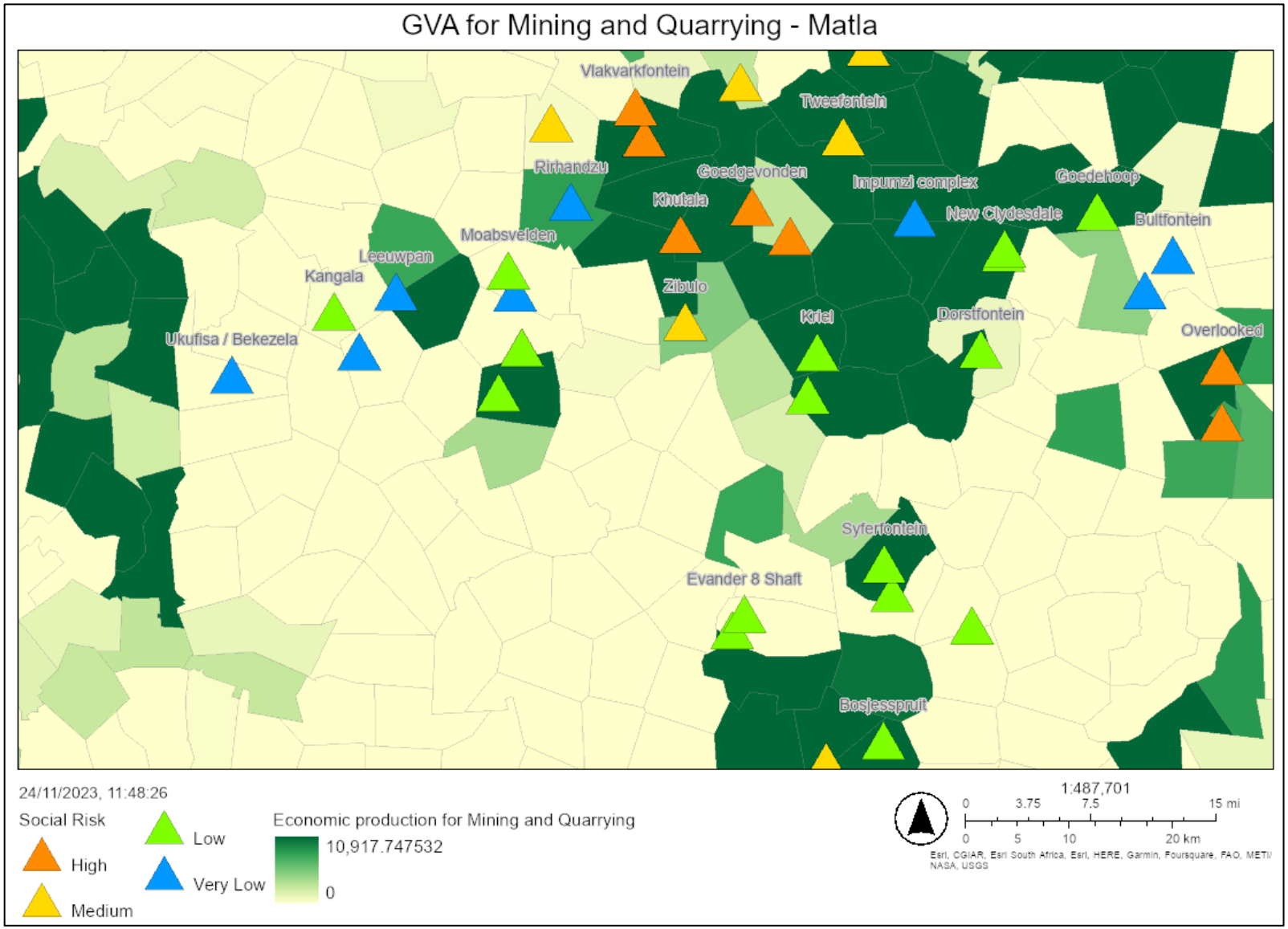

Figure 20: Economic Production for Mining and Quarrying around the Matla Mine

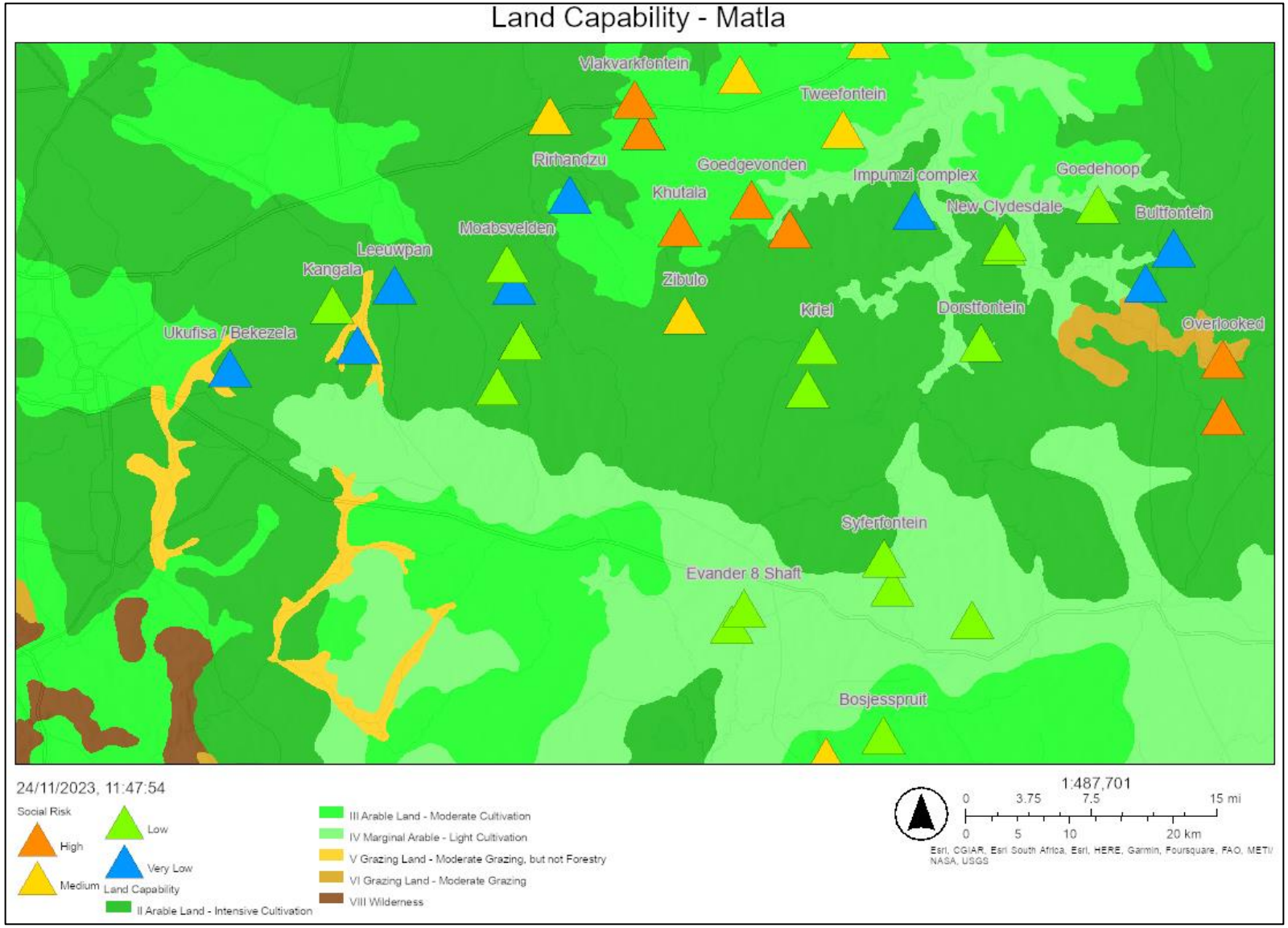

Figure 21: Land Capability around the Matla Mine

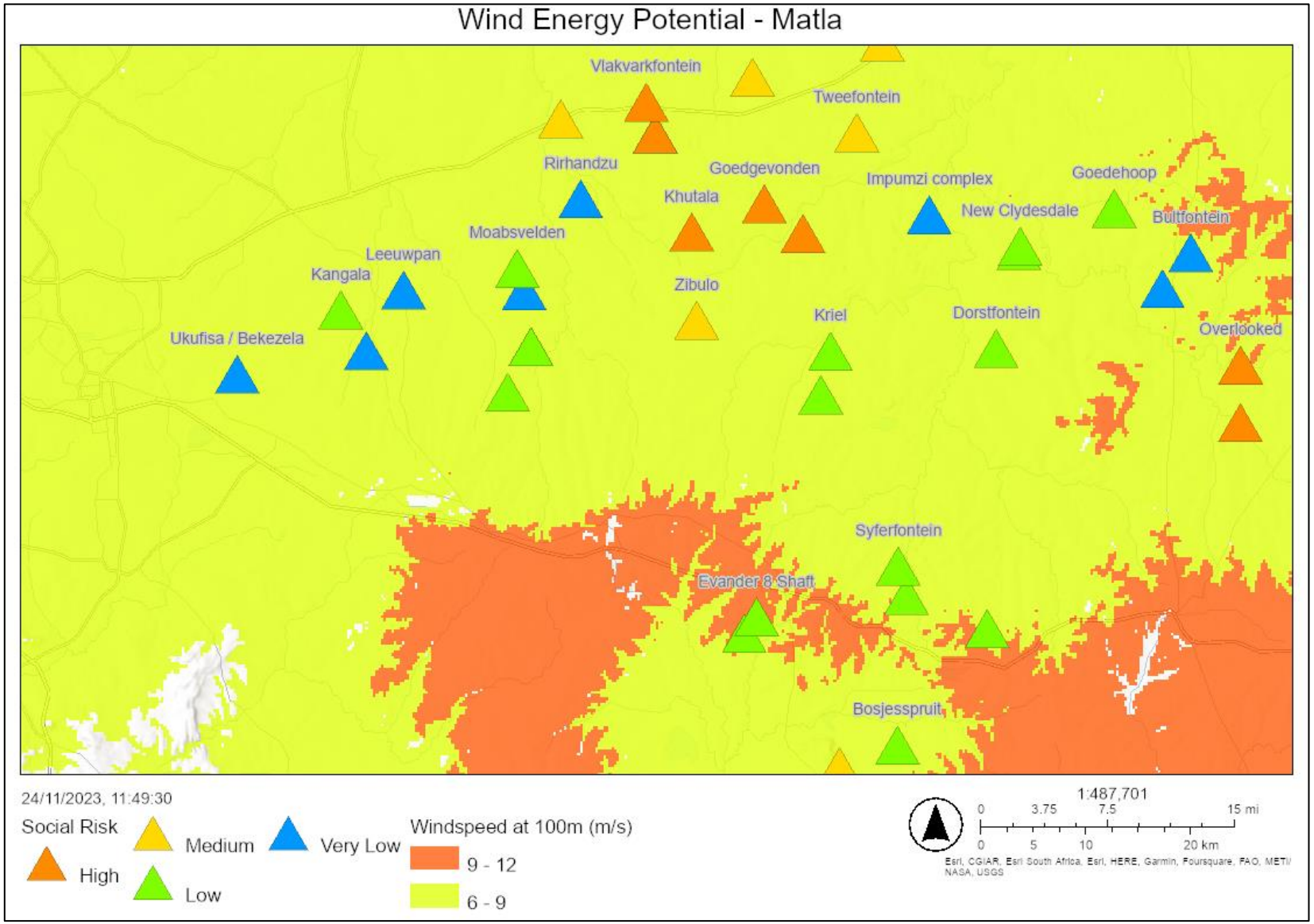

Figure 22: Wind Speed at 100 m altitude in the region of the Matla Mine

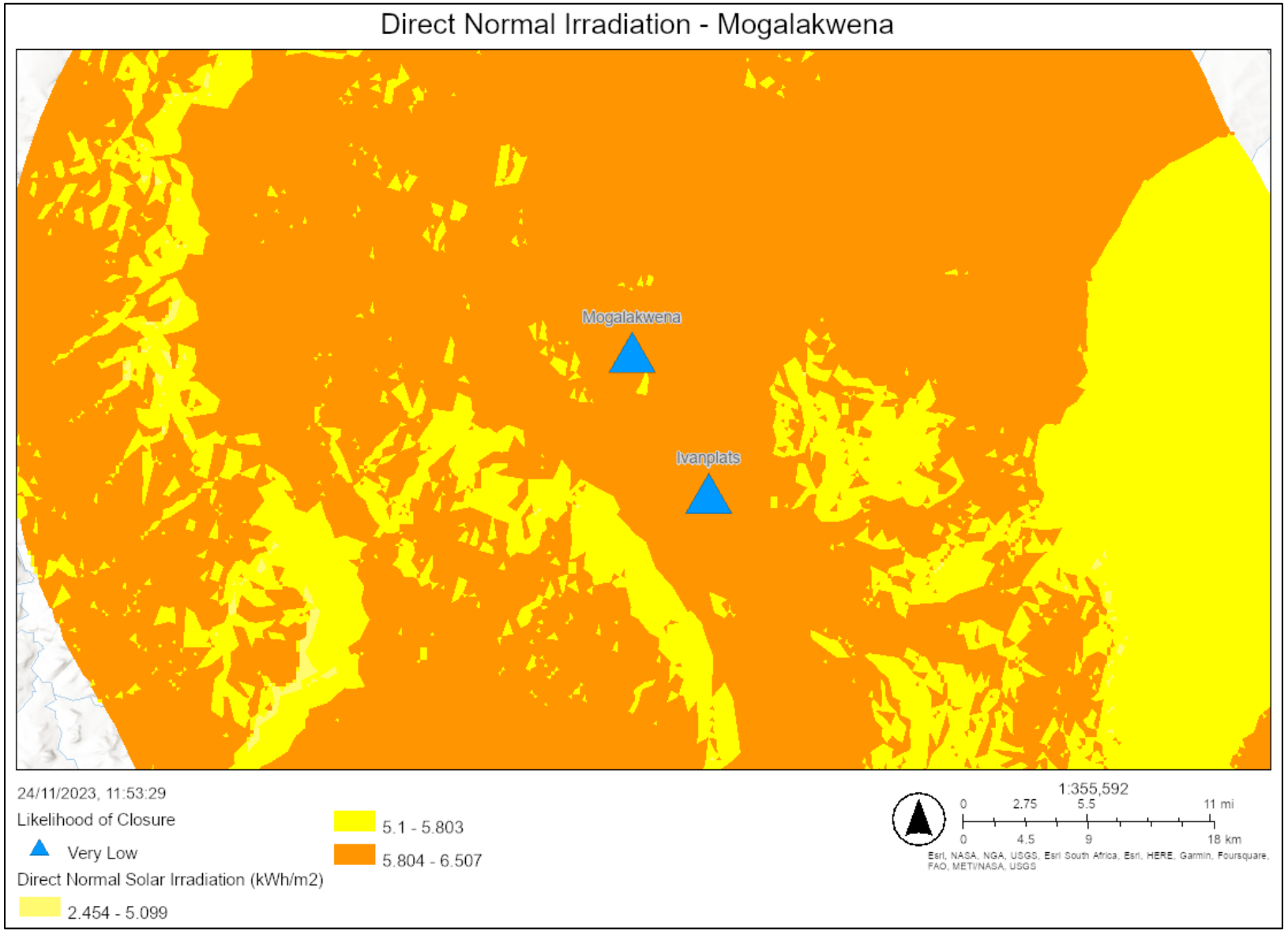

Figure 23: Direct Normal Irradiation in the region of the Mogalakwena Mine

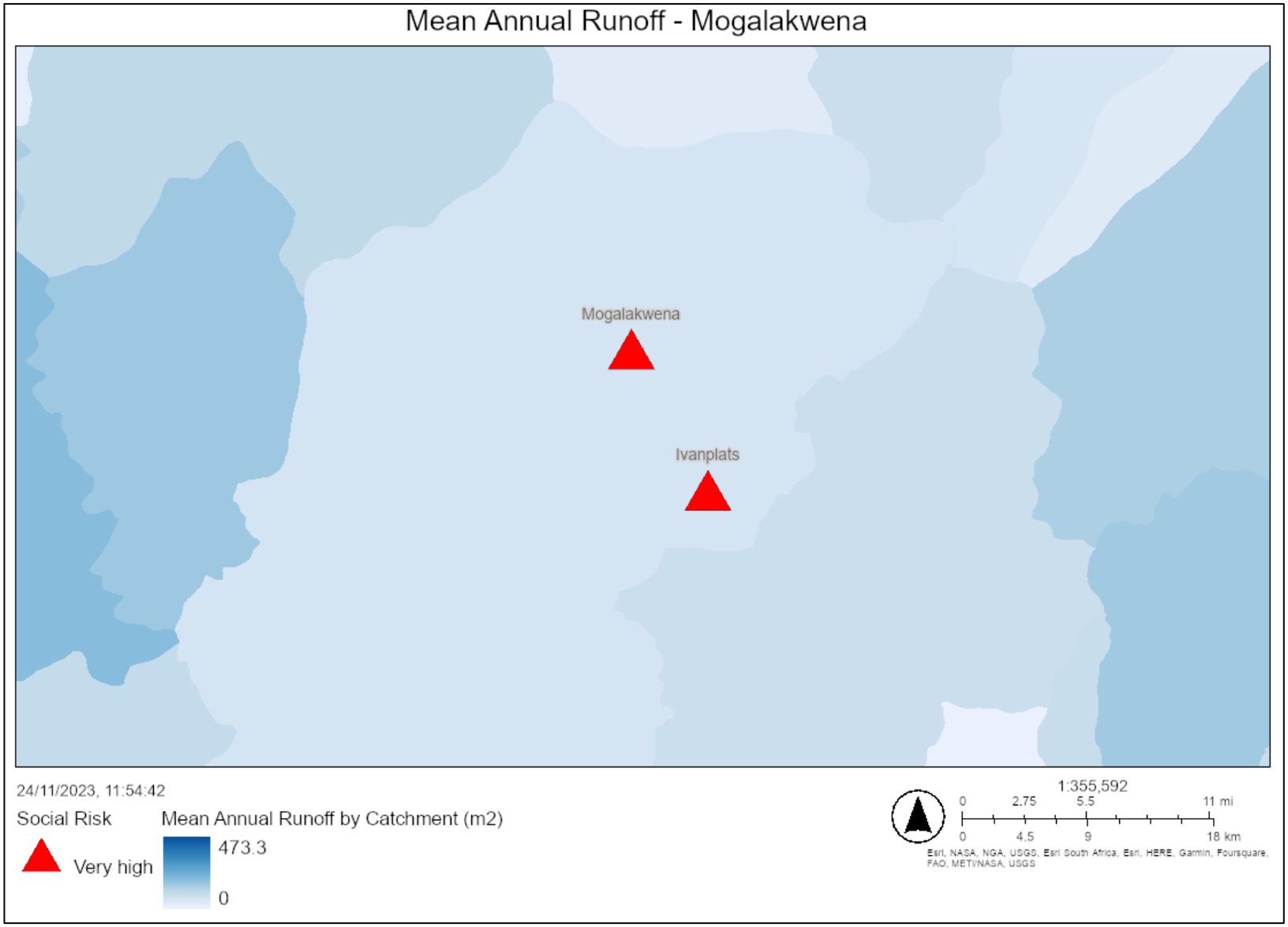

Figure 24: Mean Annual Runoff Around the Mogalakwena Mine

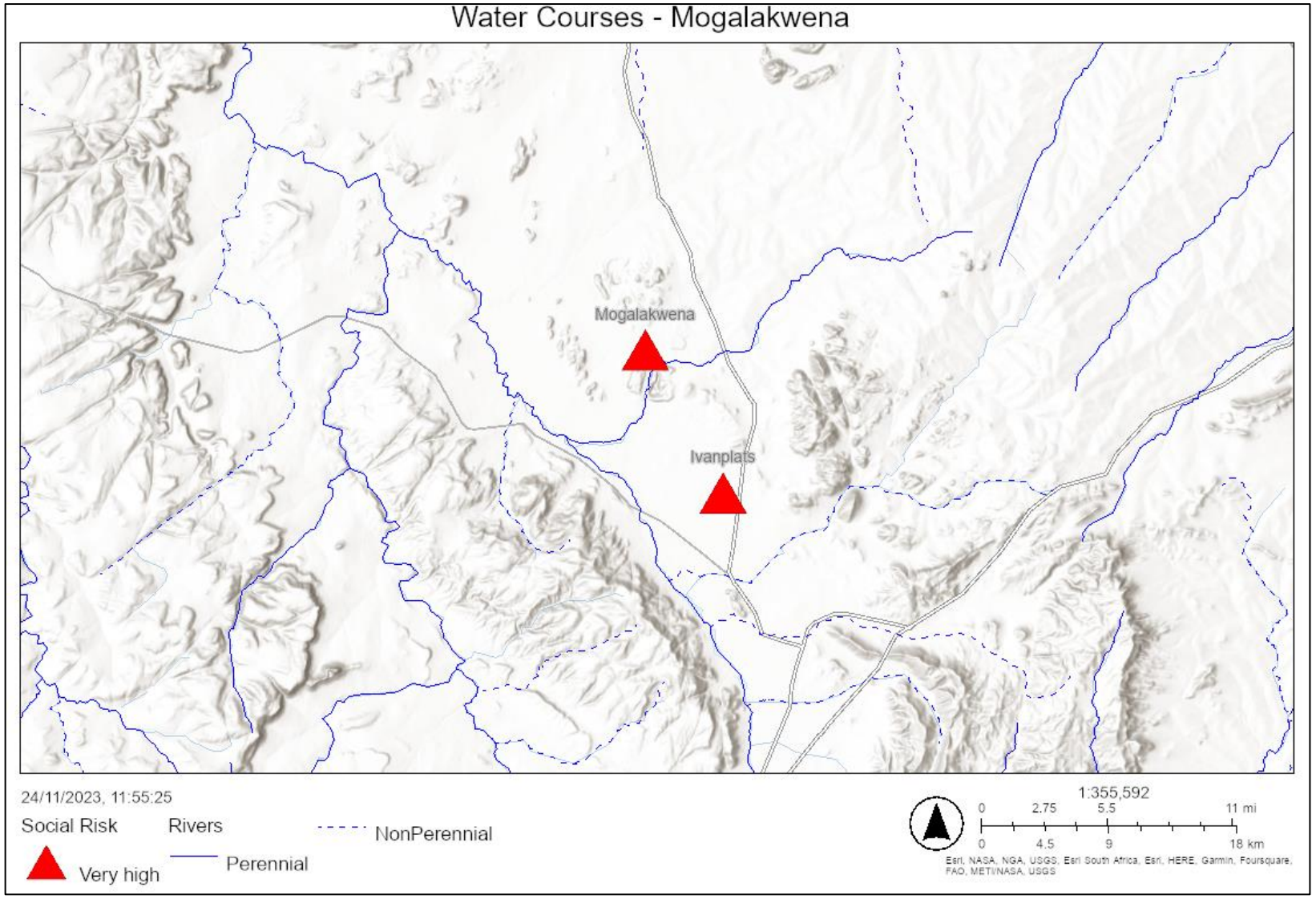

Figure 25: Water courses around the Mogalakwena Mine

4.4. Testing Interviews

Appendix D presents a summary of responses from interviewees. To retain the anonymity of interviewees, their responses are presented under the respective industry which each interviewee represents rather than their names. Sections 4.4.1 to 4.4.4 summarises the responses from interviewees with respect to the six themes of questions asked (i.e., layout and experience; information; visualisation; distribution; further resources; and general comments). As the interviews were conducted in a semi-structured manner, some questions were not asked given the time constraints with interviewees. As such, nuanced responses regarding distribution of the Atlas and further resources to be included in the Atlas are not included as standalone sections below. Rather, these themes are combined with the theme of information (Section 4.4.2).

Key areas for improvement suggested by potential users of the Atlas during the multi-stakeholder engagement workshop and testing interviews is summarised in Table 8 below.

Table 8: Key areas for improvement identified during user testing

Areas for improvement	Response
Include more local scale data in the Atlas.	The type of data concerned with by users who raised this concerned may only be obtained from the DMRE, who are notoriously uncooperative with regards to sharing local scale information regarding mining. The WRC Research Team's reference group, however, contend that the information currently in the Atlas is suitable for the purpose of the Atlas at this stage.
Compile and include tutorial video to demonstrate how to use the various widgets and tools included in the Atlas.	A User Manual (Appendix F) was developed and a link thereto was included in the Atlas. Due to time and resource constraints, a tutorial video could not be created for the Atlas as part of this study, but can be created as part of it's development moving forward.
Improve the transparency of data sources to instil trust in them by users of the Atlas.	A link to a separate 'Details' browser tab was added to each layer of data. The Details tab summarises the selected dataset and links the user to it's source.
Include more detailed information related to mine closure and the mining industry (e.g. SLPs).	Collecting and compiling this level of information for every mine and community in South Africa is beyond the scope of this study. However, links to the SLP Mining Community Toolkit developed by the Centre for Applied Legal Studies, the Minerals Council SLP portal and the DMRE guideline on SLPs were added to the Atlas.
Create a clearer distinction between some of the feature symbols on the map, which looked too similar to each other, resulting in confusion.	All feature symbols were reviewed and updated to create clearer distinctions between features.

4.4.1. Layout and experience

While one interviewee stated that the overall layout is 'clean' and easy to understand, another interviewee stated that navigation of the Atlas takes some time to understand. Both interviewees stated that they were not aware of certain features included in the layout of the Atlas – one interviewee was not aware of the search function (and suggested that it be presented as a search bar instead of a widget button) while the other interviewee was not aware of the option to change the basemap of the Atlas.

One interviewee from academia experienced difficulty in navigating the various widgets contained in the Atlas. They were uncertain about the functionality and purpose of the widgets. Once explained how

each widget works (during the interview), the interviewee felt that there is a step missing between clicking on each widget and using the widget to carry out a specific function. It was suggested that a tutorial video be included in the Atlas, however the interviewee suggested that it may not be helpful given that users of the Atlas may only watch the video once and that it is time consuming. A user manual was developed as part of the WRC project to assist users in navigating the Atlas (see Appendix F). Furthermore, the interviewee suggested that the positioning of the widgets be separated into categories of analytical tools and miscellaneous functions (i.e., the elevation profile, add data and location widgets be separated from the attribute table, capture, draw and coordinates widgets).

With regards to suggested improvements to the layout and experience of the Atlas, one interviewee suggested that selected map features be highlighted in the attribute table when it is open. Two interviewees stated that the labels of map features (such as the names of mines) were not visible at first glance or they did not appear. The Atlas is configured in such a way that the labels of map features (which have a name) are only visible once the user zooms to a certain extent on the map.

4.4.2. Information

There was a general consensus among the interviewees that the level of detail and amount of data contained in the Atlas is excellent. The interviewee who works in the consulting industry stated that the Atlas will assist in strengthening of baseline sections of reports as it provides an understanding of the environment around mining operations. The Atlas also facilitates the identification of potential cumulative impacts of mining operations on the environment. However, it was noted (by another interviewee in the government sector) that users may not trust the data contained in the Atlas, especially the data pertaining to mines and communities, which was generated by the WRC Research Team. While the details page for each data source links users to the source of data collated from external sources, an explanation of the risk ratings for mine closure was added to the Atlas once they were finalised at a later stage of the project being conducted by the WRC Research Team.

Interviewees also noted that important data and information that is useful for mine closure planning was not present in the Atlas. Firstly, a number of mines that some interviewees are familiar with were not present in the version of the Atlas that they were presented. Secondly, two themes of data were highlighted by interviewees from the renewable energy and government sectors that should ideally be included in the Atlas – in addition to the existing data contained in the Atlas. These themes include information pertaining to the right to land and mining rights, which is useful for post-closure development, and data pertaining to the socio-economic environment, including data pertaining to economic development, existing economic sectors present in areas of interest, Social and Labour Plans (SLP) for each mine, and information about the decommissioning of each mine. With regards to socio-economic information, interviewees referred to the Spatial Tax Portal which provides data pertaining to economic activity in South Africa available in a geospatial format. The Spatial Tax Portal is a project that was launched in partnership with the South African National Treasury, the Cities Support Programme, and the Human Sciences Research Council in addition to a number of secondary partnership organisations (Spatial Economic Activity Data South Africa, 2023). The interviewees conceded that, given the number of mines in South Africa, it is an immense undertaking to collect the SLP for each

mine in South Africa. Additionally, not all mining companies make their respective SLPs available to the public. It was suggested that a link to the website where the mining companies (who do make their SLPs available to the public via their website) host their SLP be included in the Atlas.

4.4.3. Visualisation

Although not many, interviewees stated a number of confusions regarding the visualisation of data in the Atlas. Two interviewees stated that they experienced difficulty in distinguishing the symbols of difference categories of mines (e.g., mines classified by likelihood of closure risk rating and mines classified by environmental risk rating) from each other. The colour coding of mining host community classification was also described as being too similar, leading to confusion by the interviewee. Another interviewee suggested that the symbology of the map features be altered to facilitate easier differentiation between the classification of categories of mines and the classification of mining host communities.

Interviewees provided feedback on the potential for data visualisation to provide insights into the data contained in the Atlas. One interviewee stated that, although viewing the data contained in the Atlas in tabular format is useful (via the attribute table), it would also be useful if users of the Atlas were given the option to view more than one attribute table at a time (i.e., view one attribute table for a particular dataset and another attribute for a different dataset simultaneously). A suggestion was also given to include a tool in the Atlas that enables users to harness data pertaining to a particular area. The interviewee stated that they would like a tool that allows them to draw a shape around a particular area that they are interested in, and have the Atlas automatically provide all the information pertaining to that particular area rather than having to go through all the datasets individually (which is a tedious task given the plethora of data contained in the Atlas). This kind of tool is useful for conducting analyses at a local scale.

4.4.4. General

Barring one interviewee who stated that the Atlas provided a notification of an error when they first tried to open the Atlas link (it is unclear exactly what the error message stated, however the issue was resolved when the interviewee reloaded the webpage in their internet browser), the overall impression of the Atlas by the interviewees was positive. Information hosted by the Atlas, such as information relating to mine tailings, was said to be useful for reporting. The widgets hosted by the Atlas, such as the elevation profile widget, was also said to be useful for analyses. With regards to post-closure land use development, it was noted by the interviewee from the renewable energy industry that while the Atlas is useful for identifying the type of industry to develop in mine closure hotspots, implementation of these developments require input from mining companies to reskill their workers to be able to work in these post-closure industries before mine closure takes place. This requires concurrence from mining companies to use the Atlas for the identification of post-closure developments and reskill their workers for the appropriate potential post-closure developments before their respective mines close.

Interviewees who are accustomed to using online GIS tools noted its similarity to other online GIS tools such as Cape Farm Mapper (Western Cape Government, 2023) and understood that it is merely a tool

to aid analyses. However, another interviewee highlighted the fact that the Atlas will indeed be used by users who are not trained to work with GIS tools in any way. It was stated that, to an untrained or poorly educated user, the perception of the Atlas may well be that it provides them with answers to their questions about mine closure.

CHAPTER 5

5. Discussion

This Chapter presents a discussion on the results of this study (Chapter 4) and the outcome of completing its scope (see Section 1.3). The following sections are structured according to the results of this study as follows: Section 5.1 discusses the final Atlas developed using the methodology outlined in CHAPTER 5 and the value it adds to the mining sector, the implications of visualising data in the Atlas, and the Atlas in relation to mine closure policy and regulation in South Africa. Section 5.2 discusses the key insights gained from various presentations of the Atlas and the feedback received in relation to the development of the Atlas. Section 5.3 presents hypothetical analyses of the maps generated using the Atlas for the three case study sites with regards to mine closure risks and post-closure development. Lastly, Section 5.4 discusses the insights gained from the user testing process.

5.1. Atlas

5.1.1. Value of a GIS-based Mine Closure Atlas for the Mining Sector

As Andreev (2021) put it, the mining industry cannot be fully developed in the absence of GIS. While the industry is well accustomed to the use of GIS, it is a relatively novel tool in the closure stage of the mining life cycle and has the potential to improve mine closure practice (Werner, et al., 2019; Poole, 2023). The South African Mine Closure Risks and Opportunities Atlas was designed to facilitate mine closure risk assessment and post-closure land use development planning in South Africa. The intention of the Atlas is to 1) make data and information pertaining to mines and mining communities, as well as their associated risks to mine closure and opportunities for post-closure land use development freely available to all stakeholders; 2) facilitate visual comparisons of the likelihood of mine closure, socio-economic risks and environmental risks of closure for all operating mines in South Africa; and 3) facilitate analytical processes for the assessment of mine closure risks and post-closure land use opportunities by means of making the relevant spatial datasets accessible and user-friendly.

All datasets used for the development of the Atlas, apart from the mine closure risk ratings which were produced by the WRC Research Team, are already available to the public. However, the Atlas presents itself as a platform which integrates these various datasets gathered from their respective sources. For context of the comprehensiveness of the Atlas, over 65 datasets in total are presented in it. These datasets include information pertaining to the South African mining industry, society, natural environment, governance and demography. It must be noted that, while the Atlas contains most of the necessary information that can potentially be used to support mine closure and post-closure land use decision-making processes, it is ultimately the broader analytical process that is conducted by users of the Atlas that drives decision-making processes. The Atlas is merely a facilitator of analytical processes and is limited in providing outright answers to complex issues associated with mine closure in South Africa. In other words, it is the users of the Atlas that make decisions rather than the Atlas making decisions for its users. This aligns with the definitions of GIS (Maguire, 1991; Burrough, 1986; Parker,

1988; Koshkariov, et al., 1989), but not that of Smith *et al*.'s (1987), which implies that GIS is used to answer queries about spatial entities contained in a GIS database system.

When compared to existing online GIS tools, it is clear that the Atlas contains the most comprehensive dataset relative to the topic of mine closure and post-closure development for South Africa at all scales, and inclusive of a broad array of aspects pertaining to the country's mining industry. In addition to acting as a data repository, the Atlas enables users to conduct analyses using its built-in functionalities enabled by the inclusion of various widgets. The Elevation widget, which identifies the elevation profile of a particular area, allows users to understand the elevation characteristics of an area of interested in. This is useful when planning for development in the post-closure phase of mining operations. The Location widget, which captures data contained in the Atlas relative to a specified area, allows users to quickly understand the characteristics of an area of interest without having to sift through the plethora of data contained in the Atlas[10]. The Print widget, which generates maps directly from the Atlas, allows users to present data from the Atlas in the form of a static map that can be used in reports and/or presentations (or any other applications outside of the Atlas).

A key characteristic which sets the Atlas apart from other GIS tools is that it is designed with the consideration of stakeholders and is configured to operate across computers, cell phones and tablets. The Atlas not only caters to diverse stakeholders but also deliberately embraces an open-access approach for the dissemination of its information, underscoring the Promotion of Access to Information Act 2 of 2000 which seeks "*To give effect to the constitutional right of access to any information held by the State and any information that is held by another person and that is required for the exercise or protection of any rights; and to provide for matters connected therewith*" (South African Government, 2000). Unlike many other GIS databases, the Atlas is not kept behind any paywalls and can be accessed by anyone at any time, with the only constraint being the requirement for a connection to the internet and a device to connect to it. The open-access nature and potential to be used on mainstream devices is an important factor to consider with respect to mining host communities, who may not have the means to access 1) powerful computers that can process large amounts of data; 2) the funds to access data that is proprietary; and 3) knowledge regarding the source of all the datasets. While the Atlas addresses these limitations, it does not provide its users with guidance on how to use and interpret the data for their unique requirements and contexts.

While the Atlas contains useful tools and data, it is limited to just that. Due to its reliance on publicly accessible data, it may not reflect the most recent or accurate information on mine closure and post-closure development. For example, the census data hosted by that Atlas dates back to 2011, when the latest census data (required at the scale of the Atlas) was made available.

Data Visualisation

While cartographic representations of regional characteristics tend to oversimplify reality, broader public discourses that support mining host communities, who are least represented in mine closure and

[10] The Location widget is limited to display datasets relative at a local scale, which this widget is intended to primarily be used for. Larger datasets are not possible to be included due to system constraints.

post-closure development planning, are sanctioned by spatial and visual analyses (Werner, et al., 2019). The Atlas facilitates this in two ways. Firstly, the Atlas makes data that is often difficult to navigate (although publicly accessible) easily and readily available by means of either searching for a particular area or panning to it on the map using the Search function. Secondly, the data is presented in an easily understandable manner in the Atlas. Effort was made to ensure that data is presented in a manner that is comprehendible to seasoned professionals and experts of the mining industry as well as mining host community members who possess low levels of education. Consideration was given to Weinstein & Sandman's (1993) seven criteria to evaluate risk as well as Ancker *et al.*'s (2006) goals of risk communication (increase understanding, change risky behaviour and encourage cooperative conflict resolution) (see Section 2.2). Based on the presentations and interviews undertaken, (see Sections 5.2 and 5.4), it can be assumed that the Atlas achieves Ancker *et al.*'s (2006) goals of risk communication through its presentation of information in an easily comprehendible manner and can be used to facilitate decision-making processes that results in the aversion of risky behaviour. Additionally, the uniformity of information presented to all users of the Atlas facilitates the cooperative conflict resolution as all stakeholders have access to the same information via the Atlas.

The tangible information contained in the Atlas also allows mining host communities to voice their concerns about mine closure. Mining host communities are aware of the environmental and social risks of mine closure, but often do not have the means to demonstrate this to authorities responsible for mine closure. The Atlas fills this gap by presenting users with evidence to support the perspectives of stakeholders regarding their subject of interest on the theme of mine closure (Esau, et al., 2023).

5.1.2. Policy

While the Draft National Mine Closure Strategy (2021) focuses on regional scale management of mine closure risks and post-closure land use opportunities, the Atlas facilitates analyses of mine closure risks and post-closure land use opportunities at national, regional and local scales. While management at a regional scale offers a broad approach to the management of impacts that may occur across multiple mines in the same region (Department of Mineral Resources and Energy, 2021) (see Figure 26 illustrating mineral clusters of South Africa and Figure 27 illustrating mineral clusters and mine closure hotspots of South Africa generated using the Atlas), local scale impacts of mine closure are not adequately accounted for in the model proposed by the Draft National Mine Closure Strategy (2021). To address this gap in strategy, regional management of mine closure hotspots is proposed. A regional regulatory body will be responsible for the implementation of the finalised National Mine Closure Strategy and may use the Atlas to aid decision-making regarding mine closure and post-closure land use at a regional scale. However, it will be the responsibility of mining host communities and other stakeholders operating at a local scale to provide inputs at a local scale regarding decision making around mine closure and post-closure land use. The Atlas is useful in this regard as it provides information and facilitates analyses at a more granular scale, while also facilitating regional analyses, addressing concerns at a local scale and providing input to mine closure and post-closure development planning at a regional scale. Section 5.3 provides examples of how the Atlas can be used to identify environmental, social and economic conditions at a local scale. Appendix G provides examples of how

widgets incorporated in the Atlas facilitate analyses for mine closure and post-closure development planning.

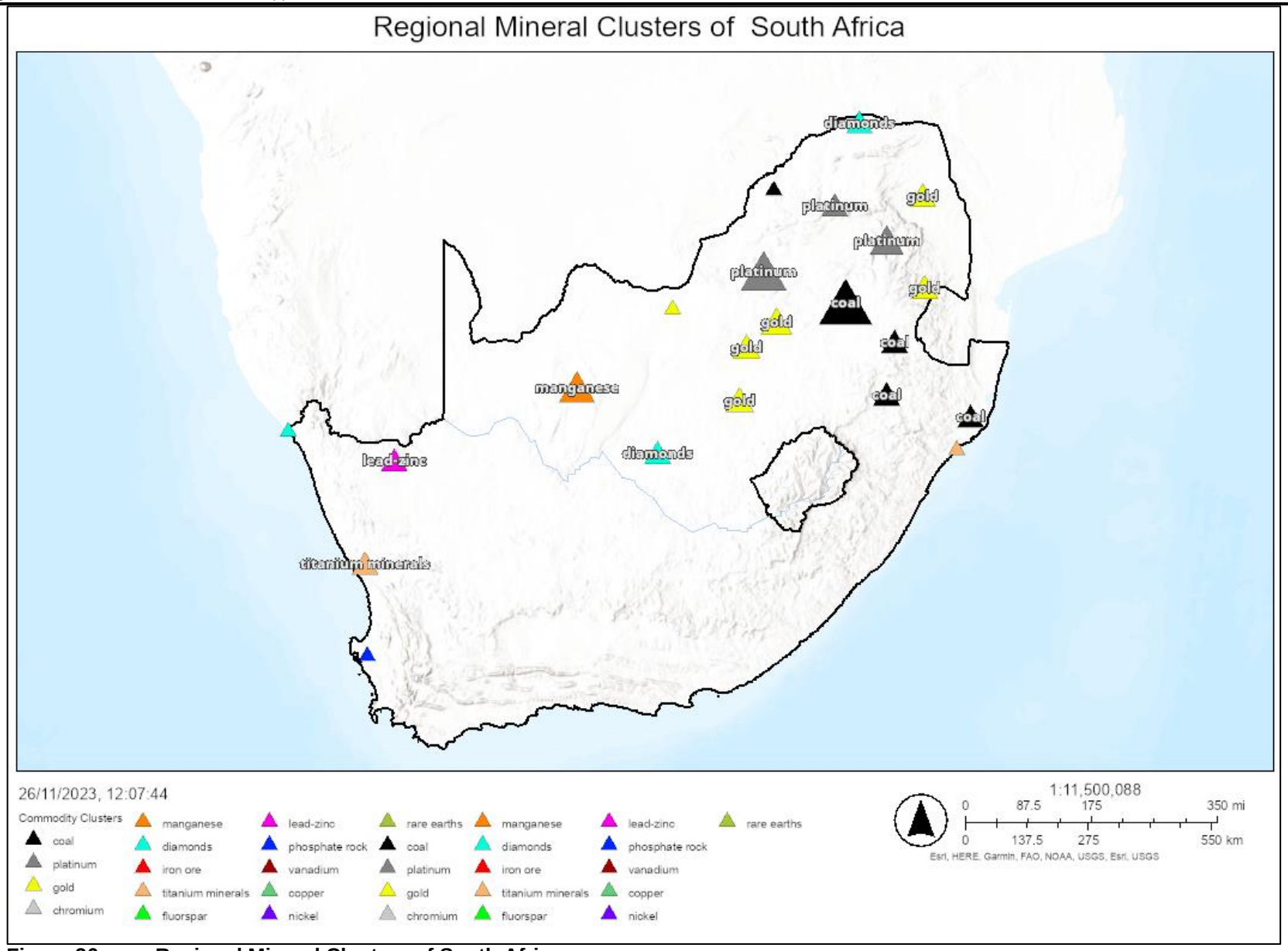

Figure 26: Regional Mineral Clusters of South Africa

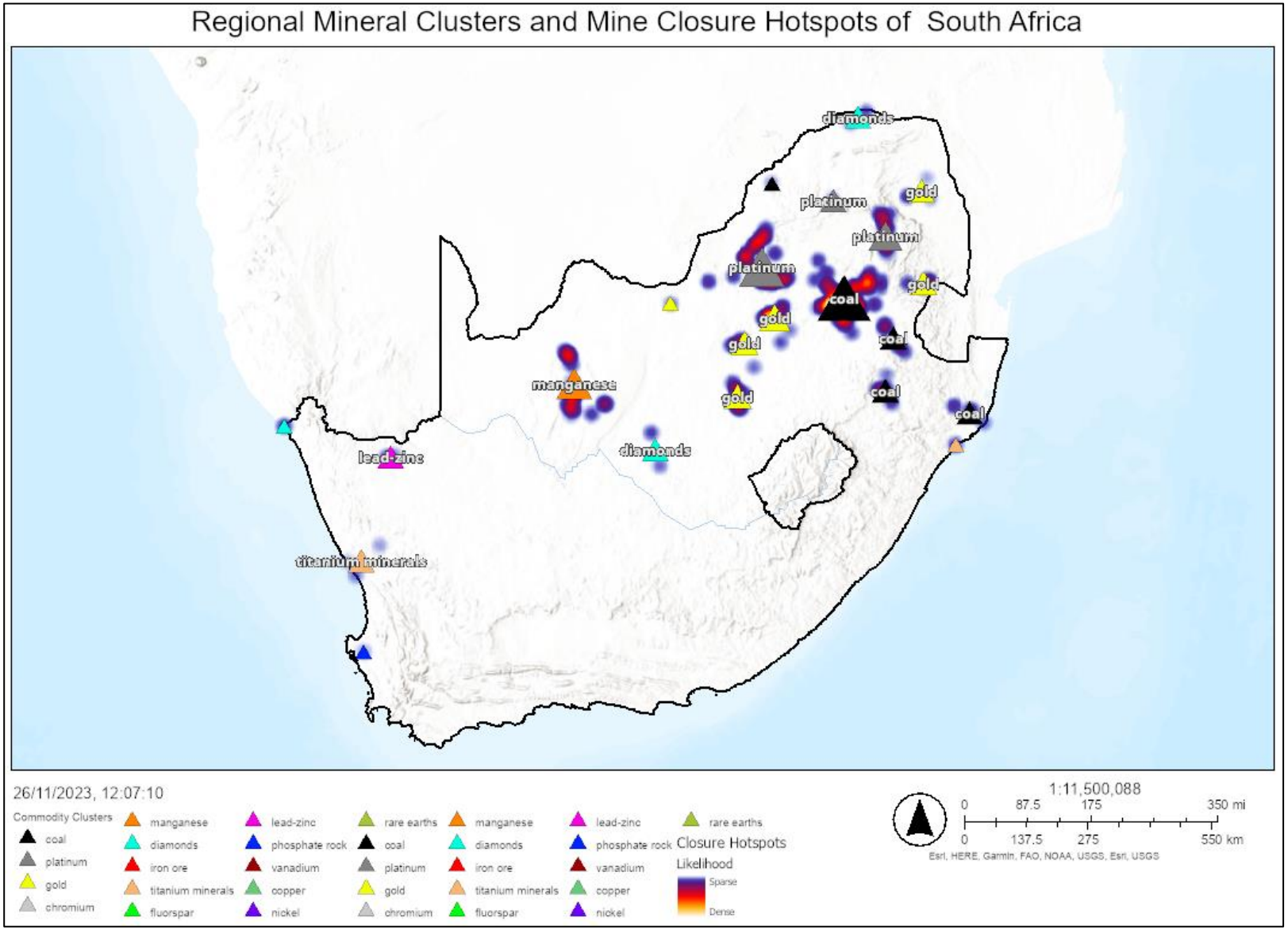

Figure 27: Regional Mineral Clusters and Mine Closure Hotspots of South Africa

5.2. Presentations

The Atlas was presented to a variety of potential users who provided feedback and insights on its usability, purpose and design. The WRC Research Team's reference group comprised of seasoned experts from the South African mining industry and academia while the online multi-stakeholder engagement workshop consisted of potential stakeholders of mine closure from industry to mining host community members. The presentation of the Atlas at the Mine Closure 2023 conference facilitated feedback to be garnered from internationally acclaimed experts in the field of mine closure and post-closure development. A common theme that is present in the feedback from all three presentations is that the Atlas is an excellent initiative both in South Africa and beyond.

Feedback from the multi-stakeholder engagement workshop indicated that the quality of data contained in the Atlas is not sufficient. It must be noted that the data that workshop attendees were concerned with is not publicly available and may only be obtained from the DMRE, who are notoriously uncooperative with regards to sharing local scale information regarding mining. The WRC Research Team's reference group, however, contend that the information currently in the Atlas is suitable for the purpose of the Atlas at this stage. Of course, the Atlas must be periodically updated with new data that is released to the public domain and updated versions of the datasets currently hosted by the Atlas.

Contrastingly to local scale concerns raised by participants at the online multi-stakeholder engagement workshop, audience members at the Mine Closure 2023 Conference were concerned with the conceptual aspect of the development and use of the Atlas. A common theme of issues raised at the Conference was the assumption that the Atlas may provide the answers to all questions around mine closure and post-closure development. It was repeatedly clarified that the Atlas is intended to facilitate decision-making by its users rather than making decisions by itself (i.e., without human input). It must be emphasised that although the Atlas is intended to be used by all stakeholders, the decisions made based on or supported by the data contained in the Atlas ultimately lies in the hands of stakeholders and responsible authorities.

5.3. Case Studies

The maps generated using the Atlas (see Section 4.3) provide an opportunity for analyses of the areas around the three mines chosen as case study sites – Kusasalethu, Matla and Mogalakwena. This section offers an example of the type of analyses that can be undertaken using the Atlas and the maps that can be generated using it. It must be noted that the analyses provided below are hypothesised based on the maps illustrated in Figure 17 to Figure 25. There are many factors which influence decisions regarding post-closure land use development, including but not limited to the needs and desires of mining host communities, the state of land impacted by mining operations and existing infrastructure. The sections below are organised as follows: first, an analysis of the selected data for Kusasalethu mine will be discussed (Section 5.3.1), followed by the Matla (Section 5.3.2) and Mogalakwena (Section 5.3.3) Mines. For each mine, hypothetical possibilities for post-closure land use development are discussed as well as suggestions for considerations regarding the risk of mine closure.

5.3.1. Kusasalethu

The Kusasalethu mine poses a medium risk to the environment should it close. There are two Protected Areas in relatively close proximity to this mine – the Boskopdam Nature Reserve to the west and the Tweefontein Private Nature Reserve to the southeast. There is also a NPAES area located to the west of the mine – the Vaal Grasslands NPAES area. Grazing Capacity in the immediate surroundings of the mine is relatively low, with a score of 8 – 10. There are sparse patches of 11 – 13 scored Grazing Capacity to the northeast and northwest and Transformed Rangeland areas further away from the mine in all directions. According to the SANBI Mining and Biodiversity Guidelines (2012), biodiversity in the immediate surroundings of the mine is classified as being of high importance, with mining operations in the area posing a high risk to biodiversity. Biodiversity further south of the mine is classified as being of highest importance, with mining posing the highest risk to biodiversity in that particular area.

Based on the above analysis of the data contained in the Atlas, it can be deduced that, should the Kusasalethu mine close, livestock farming may not be the most suitable option for an alternative economy in the region, given the low Grazing Capacity score. This may be due to the vegetation not being suitable for livestock grazing. This poses an inherent issue to the mines host communities (there are more than 10 in close proximity to the mine, many of which Cole & Broadhurst (2020) classify as mine villages), who may well require an alternative economy in due course given the mine's high likelihood of closure. An added complexity to the matter is that the SANBI Mining and Biodiversity Guidelines (2022) indicate that the risk of expanding the mine for further mineral extraction (should any more gold be present in the ground surrounding the mine), which subsequently increases the LoM, may be detrimental to the integrity of the area's biodiversity. This is supported by the presence of the nearby Vaal Grasslands NPAES to the west of the mine.

The result of the above analysis indicates that an alternative economy in the region of the Kusasalethu mine must account for the sensitivity of the natural environment of the region. The alternative economy would need to be of low impact to the environment, also considering that livestock grazing is not a suitable option.

5.3.2. Matla

The Matla mine possesses a low social risk, should it close. The economic production for mining and quarrying in the region around the mine is very good, with the map (Figure 20) illustrating a dark green shade towards the north and east of the mine, and lighter shades of green towards the east and south. Land Capability is excellent, with the surrounding areas of the mine being classified as arable, with extensive cultivation possible. The average wind speed of the area is relatively good at 6 – 8 m/s at 100 m elevation. Given these characteristics, it is clear that, although the areas around the Matla mine are reliant on mining activity for economic prosperity at present, the possibility of transitioning to a more crop production based regional economy in the post-closure phase is feasible given the excellent Land Capability of the region. Of course, other factors, such as the supply and delivery of seeds and water availability, must also be considered (water supply possibilities can be analyses using the Atlas by viewing the water related datasets). The withdrawal of mines from the region also offers an opportunity

for the establishment of renewable energy sources in the area – an avenue that is being pursued as part of the transition to clean energy production in South Africa (Cole, et al., 2023) – as land may become available for the establishment of solar and/or wind farms. The establishment of wind farms in the region around Matla is particularly viable, given the good wind speed at 100 m elevation and the existing connection to the electricity grid in the region remnant of mines in the area, should they close.

5.3.3. Mogalakwena

The Mogalakwena mine has a very low likelihood of closure. However, planning for closure of the mine should still be undertaken, as per the ICMM best practice (2019).The region around the mine is exposed to a relatively good amount of Direct Normal Irradiation, which ranges from 5.804 kWh/m^2 to 6.507 kW/m^2. Mean annual runoff in the catchment area is poor as indicated by the light shade of blue presented in Figure 24. A perennial river flows pass the mine in close proximity from west to northeast. Based on these characteristics, opportunities for post-closure land use development can be considered as well as resources that must be protected. The good DNI levels in the region supports motivation to develop a solar farm in the region. However, the necessity of a solar farm at the time of the mine's closure must be considered (this may depend on the state of South Africa's greenhouse gas emissions and the state of the country's electricity generation at the time of closure). With regards to the needs of mining host communities in the region, water supply is an important factor to be considered given the low levels of runoff in the region. In other words, communities in the region need to rely on water supplied by adjacent catchments, which requires the installation of the suitable infrastructure (e.g., pipelines and canals). The presence of rivers in the area around the mine, particularly the river flowing in very close proximity, must be protected from the adverse impacts of mine closure, especially the possibility of AMD, which may pollute the river that is possibly a source of water for communities in the region.

5.4. Testing Interviews

The selection of interviewees aligns with the views of McInerny *et al.* (2014), Spiegelhalter *et al.* (2011) and Lipkus & Hollands (1999) who emphasise the importance of cross-discipline collaboration for the development of effective visual communication. In addition to the broad spectrum of participants of the multi-stakeholder engagement workshop and the Mine Closure 2023 conference, the five interviewees who tested the Atlas at a more in-depth scale provided a solid foundation of experts from various fields to participate in the development of the Atlas. It must be noted that, in agreement with Ancker *et al.* (2006), although valuable input was provided by various stakeholders regarding the Atlas, care was taken to evaluate their input in relation to the intended goals of the Atlas. For example, interviewees noted that more information regarding mining and land rights should be included in the Atlas. This information is notoriously difficult to obtain, particularly at a national scale, and was subsequently omitted from the data layers pertaining to operating mines in the Atlas. Rather, the WRC Research Team combined the operating mines database published by the DMRE database of operating mines, which includes cadastral information pertaining to each mine in South Africa, with their own data on operating mines (see https://www.dmr.gov.za/mineral-policy-promotion/operating-mines). Notably, this only includes cadastral information pertaining to operating mines. The DMRE is meant to be releasing

an updated mining cadastre in 2024, which is said to contain in-depth information on cadastral information pertaining to all operating mines in South Africa. Interviewees also noted that data pertaining to SLPs should also be included in data layers associated with operating mines in the Atlas. The collection of SLPs for all mines in South Africa is beyond the scope of this study. Instead, various links to information regarding SLPs is included as auxiliary (supporting) information within the Atlas. This includes links to the SLP Mining Community toolkit (Center for Applied Legal Studies, 2022), the Minerals Council SLP Portal (Minerals Council South Africa, 2023) (which contains links to SLPs for operating mines who have provided them to the Minerals Council), and the DMRE guideline on SLPs (Department of Mineral Resources and Energy, n.d.). Other recommendations made by interviewees sparked innovative ideas for the development of the Atlas, such as the inclusion of the 'Location' widget. This type of tool was suggested by multiple interviewees to be included in the Atlas. It is a specialised tool that will aid local scale analyses of mine closure risks and identification of post-closure land use opportunities.

Issues regarding the visualisation of data in the Atlas was also highlighted by interviewees. While it is difficult to colour code all the datasets to distinguish them from each other, it must also be noted that consideration was given to individuals who experience colour blindness. Effort was made to distinguish the colours of map features as much as possible, however this does become difficult given the plethora of data contained in the Atlas. This issue may have been addressed if an artistic specialist was involved in the development of the Atlas (as suggested by Spiegelhalter *et al*. (2011)), however this was beyond the scope of this project. It should be noted that, besides the confusions regarding colour coding, interviewees were generally satisfied with the layout of the Atlas and found it easy to use.

The Atlas possesses and displays information that is important to many sectors associated with mining. The consolidation of all the data and the possibility to perform various analyses using the Atlas makes it a tool that is potentially pivotal to the sectors associated with the mining industry. Thus, in accordance with Gualtieri's (2009) characteristics of good UX design, feedback from interviewees indicate that the Atlas is a useful tool in the mining industry and associated sectors that is intuitive in its operation and possesses a high degree of desirability due to the data it contains, its ability consolidate the data, and the analytical functions that can be performed using the Atlas. Interviewees that are accustomed to the use of similar GIS tools (such as the Western Cape Provincial Government's Cape Farm Mapper) indicated their satisfaction with the similarities with other GIS tools, stating that the method of use of the Atlas is not too dissimilar from other GIS tools (i.e., it is not difficult to learn how to use the Atlas). Based on this feedback, the Atlas fulfils its objective of making information regarding mine closure easily comprehendible by being user-friendly in nature.

CHAPTER 6

6. Conclusion and Recommendations

6.1. Conclusion

Table 9 below summarises the key research questions specified in Section 1.4 how they were addressed in this study.

Table 9: Key questions of this study and how they were addressed

Research Question	Response
What data should be included in the Atlas to aid the assessment if mine closure risks and opportunities for post-closure land use development in South Africa?	One of the key objectives of the Atlas is to make data freely accessible to all stakeholders. Therefore, only publicly available and accessible data was used in addition to data pertaining to mines in South Africa collected by Cole & Broadhurst (2020) and the WRC Research Team. In addition, Table 5 provides a criteria for selecting which data to be used. Stakeholders engaged with during the study also provided input on the data used.
How can the Atlas be designed to best support decision making and communication of information associated with mine closure planning?	A comprehensive literature review was conducted to identify the best solution to communicating the data which ultimately supports decision making processes. Mader & Eggnik's (2014) concept of CT was adapted for the development of the Atlas given it's iterative approach to development. Numerous iterations of the Atlas was developed and presented to – and tested by – potential users.
How can the Atlas conform with current legislation and mine closure planning practices?	The Atlas contains data that can be interpreted at both a local and regional scale – the latter which forms the basis for current South African legislation pertaining to mine closure planning (Department of Mineral Resources and Energy, 2021). Local scale information is useful to mine closure planning to individual mines and mining host communities to understand localised impacts.
How will the Atlas be made to be accessible and comprehensible to all the stakeholders?	The Atlas, as is the case with many GIS tools, is a tool that integrates a large amount of information about real-world circumstances derived from numerous sources. The information used in the Atlas is publicly available, allowing the Atlas to be freely available to anyone with a smartphone, tablet or computer / laptop to access it via the internet. However, this is also a limitation of the Atlas given that many mining host communities are entrenched with poverty and do not have access to the necessary hardware and / or the internet. In terms of comprehension, considerations was given to Weinstein & Sandman's (1993) criteria to evaluate risk and Ancker *et al.*'s (2006) goals of risk communication to ensure that the Atlas is comprehensible to all stakeholders. Based on responses from the stakeholder engagement activities undertaken for this study, it can be assumed that the Atlas achieves Ancker *et al.*'s (2006) goals through its presentation of information in an easily comprehendible manner.

The purpose of this study was to develop a National Mine Closure Risks and Opportunities Atlas for South Africa that can be used by all stakeholders involved with mine closure and post-closure land use planning. The Atlas is intended to be used to aid decision-making processes. A variety of experts and stakeholders of the mining industry were engaged with by means of presentations and interviews to understand their requirements that can be fulfilled using the Atlas, which was developed accordingly.

Key positive outcomes of the Atlas' testing during the multi-stakeholder engagement workshop and as part of testing interviews conducted for the development of the Atlas include that the:

- Overall layout was described as being simple and easy to understand;
- Level of detail and quantum of data contained in the Atlas is impressive;
- Viewing of data in tabular format as well as by looking at the layers is useful; and
- Atlas will be useful for reporting purposes.

The overall result of user testing indicated that interviewees were mostly satisfied with the version of the Atlas presented to them, lauding the quantum of data it contained at the time and recommending additional data that can be included. Its user interface was scrutinised, with suggested improvements noted and implemented in the final Atlas. Concerns raised about the limitation of accessibility of the Atlas to mining host communities who do not have access to the required hardware (computer, laptop, tablet and / or smartphone) and / or the internet is noted. However, this is a broader systematic issue that cannot be addressed within the scope of this study.

Data included in the Atlas was considered in with respect to the requirements of and recommendations made by industry experts and stakeholders. Careful consideration was given to the user interface of the Atlas to ensure that data pertaining to mine closure risks and post-closure land use opportunities are comprehendible.

There was a consensus among all industry experts, academics and stakeholders involved in this study that there is a need for a tool such as the Atlas in South Africa as well as internationally. With the development of technology, the Atlas may become more sophisticated over time while maintaining its integrity to user experience. However the Atlas develops going forward, the core principles of considering the requirements of stakeholders involved with mine closure, and mining host communities in particular, must remain constant. Mining host communities are the most affected by mine closure and it is imperative that they are considered in the development of the Atlas. The data contained in the Atlas and the various functionalities that facilitate analyses is integral to informing and/or supporting decision-making processes associated with mine closure and post-closure land use planning by producing tangible evidence of environmental and socio-economic risks of mine closure (as well as current conditions). The data also enables analyses and information dissemination at all scales, making it a useful tool in decision-making processes. It also empowers mining host communities to participate in decision-making processes through its potential to be used on smartphones in instances where access to laptops and personal computers is not possible – which is often the case in South African mining host communities.

This study has shown that the Atlas is a potentially important tool for mine closure planning. Its capabilities empower its users to provide inputs on decisions around mine closure by utlising key data and uncovering hidden patterns regarding the social and natural environments by visually layering datasets. It has the potential to inform mine closure planning in line with the Draft Mine Closure Strategy for South Africa and enables the those most impacted by mine closure to emphasise their concerns using material evidence. Mining companies may also realise their impact on the environment and society by visually comprehending the characteristics of their immediate surroundings. It is clear that the Atlas is a tool that aids the facilitation of best practice mine closure planning and post-closure land use development.

6.2. Achievement of Research Goals

The main tasks associated with this research project (as specified in Table 1) include collecting quantitative data and developing a tool guided by feedback from potential users of the tool garnered through various presentations and interviews using GIS to visualise this data. Chapter CHAPTER 3 describes the methodologies used to achieve this, with the main outcome of this research project being the Atlas, which integrates a vast amount of data that is otherwise fragmented across various information sources. By visualising the various datasets, the Atlas can be used to aid the quantification of mine closure risks and assist in planning for post-closure land use opportunities.

The Atlas enables its users to access a vast array of information imperative to mine closure planning. Furthermore, its functionality allows users to interrogate multiple datasets at a time, enabling comprehensive and cohesive analyses of mine closure risks and post-closure land use opportunities, aiding the mitigation of negative socio-economic and environmental impacts.

6.3. Limitations

This study is an ambitious undertaking for a Master's research project. Time and resource constraints present a number of limitations, including the accuracy and validity of quantitative data sources, it's static illustration of environmental, social and economic conditions and lack of guidance on interpretation by less educated users. It should be noted that, while the Atlas contains a plethora of data, this data was derived from external agencies / organisations and was not generated as a result of this research project. Responsibility of the quality of the data is therefore on the onus of the data providers rather than the researcher.

The methodology used to develop the Atlas is somewhat limited as there is a lack of representation by local mining host communities in the stakeholder engagement activities. Recommendations to address these limitations are discussed in Section 6.4.

6.4. Recommendations

The following recommendations are made for further development of the Atlas based on the findings of this study.

6.4.1. Access and interpretation

Given that the Atlas is a novel tool that is the first of its kind in South Africa and even globally, awareness of its existence may need to be promoted – particularly in mining host communities. While several options were suggested by participants of this study to promote awareness of the Atlas, it is clear that third party endorsement is required to create awareness. This third party would need to be independent from mining companies (who may perceive the Atlas negatively given its potential to reveal negative impacts of their operations) and must be concerned with the wellbeing of the natural environment and society without financial influence. The third party would need to be an entity such as a government organisation and/or an NGO who can create awareness of the Atlas by means of local community meetings, community forums, school presentations and social media. Training sessions on how to use the Atlas can also be facilitated by the third party on how to interpret data in the Atlas and what the various tools in the Atlas can do.

6.4.2. Maintenance and improvement over time

Due to the data hosted by the Atlas is sourced from various entities, and the development of GIS software over time, the Atlas will require periodic updates. Updates to data hosted by the Atlas that is made by their respective sources will not reflect in the Atlas as it is a separate hosting platform. The updated data will need to be processed in the ways outlined in this study and added to the Atlas thereafter. Each data source may provide updates to their data at different times. Additionally, new datasets relevant to mine closure risks and post-closure land use opportunities should be added. While every effort has been made to include the relevant datasets, new data is published on a regular basis by various entities across the world and in South Africa.

Continuous improvements to the user interface should also take place to facilitate improved user experience (this should be done with consideration of users of the Atlas, as this study has done). A visual artistic professional should also be involved in the improvements made to the Atlas to increase its visual appeal. It is therefore recommended that the Atlas be updated annually, with a review of each dataset it hosts, the addition of new data and improvements to the user interface.

6.4.3. Stakeholder Inclusivity

While numerous engagements with potential users of the Atlas was undertaken as part of this study, it is noted that representation by mining host communities and government organisations is limited. This is largely due to time constraints and difficulty in contacting these stakeholders. While some representation was made by mining host communities during the multi-stakeholder engagement workshop (see Section 4.2) further development of the Atlas should include more extensive engagement with NGOs and civil society organisations who represent local mining host communities in user testing and interview processes.

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Appendices

Appendix A:
Data Hosted by the Atlas

Theme	Dataset(s)	Year last collected/updated	Data sources	Original format
Operating Mines	Operating mines classified by commodity, likelihood of closure risk, environmental risk of closure, social risk of closure and mine closure hot spots	2023	Cole & Broadhurst (2021)[11]; Cole (2024)	Comma-separated values (csv)
	Mine site boundaries and features	2022/2023	Tang & Werner, (2023); Maus *et al.* (2022)	Shapefile
	Tailings Storage Facilities	2023	Global Tailings Portal (GRID-Arendal; Investor Mining and Tailings Safety Initiative, 2023)	csv
	Processing plants	2022	South African Department of Mineral Resources and Energy (2022)	csv
Communities	Mining Host Communities	2023	Cole & Broadhurst (2021)[1]; Cole (2024)	csv
	Main places; sub places	2011[12]	Statistics South Africa Census Spatial Data (Frith, n.d.)	Shapefile; csv
Administrative Boundaries	Provinces; District municipalities; Local municipalities; Farms; Former homelands	2018	Municipal Demarcation Board (2022)	Shapefile
Water	Strategic Water Source Areas;	2017	Water Research Commission (South African National Biodliversity Institute, 2017)	Shapefile
	Mean Annual Runoff; Mean Annual Rainfall; Water stress	2018	Cole, et al., 2018; (2018)	Shapefile
	National Freshwater Ecosystem Priority Areas	2011	South African National Biodiversity Institute (SANBI) (2011)	Shapefile
	Mine Water Threat;	2018	Water Research Commission (Water Research Commission, 2018)	Shapefile
	Rivers; Dams; Water Management Areas	N/A	South African Department of Water and Sanitation (2012)	Shapefile
Land	Land capability	2015	South African Department of Agriculture, Forestry and Fisheries (2015)	Shapefile
	Seismic Hazard	2023	United Nations Environmental Programme (2023)	Shapefile
	Morphology	1983	South African Environmental Observation Network (2023)	Shapefile

[11] Although formally published in 2021, the authors updated their dataset in 2023.
[12] It is noted that the 2022 census data was released in 2023. However, local scale data, which was required for this study, was not published by Statistics South Africa at the time of this study. The spatial datasets were downloaded from https://census2011.adrianfrith.com/

Theme	Dataset(s)	Year last collected/updated	Data sources	Original format
	Grazing Capacity	2017	South African Government (2017)	Shapefile
Biodiversity	Ecosystem and Critically Endangered Ecosystems	2018	SANBI Biodiversity GIS (2018)	Shapefile
	Important Bird Areas	2015	SANBI Biodiversity GIS (2015)	Shapefile
	Mining and Biodiversity Guidelines	2012	SANBI Biodiversity GIS (2012)	Shapefile
	National Protected Areas Expansion Strategy	2010	SANBI Biodiversity GIS (2010)	Shapefile
	Protected areas; Conservation areas	2023	South African Department of Forestry, Fisheries and the Environment (2023)	Shapefile
Energy	Power lines;	2016	OpenStreetMap Wiki (2023)	Shapefile
	Existing Power Plants (coal, solar, wind, nuclear, hydro)	2023	Global Energy Monitor (2023)	Shapefile
	EIA Applications for Renewable Energy Development	2023	South African Department of Forestry, Fisheries and the Environment (2023)	Shapefile
	Renewable Energy Development Zones	2018	South African Department of Forestry, Fisheries and the Environment (2023)	Shapefile
	Strategic Transmission Corridors	2018	South African Department of Forestry, Fisheries and the Environment (2023)	Shapefile
	Strategic Gas Pipeline Corridors	2018	South African Department of Forestry, Fisheries and the Environment (2023)	Shapefile
	Solar energy potential (Direct Normal Irradiation)	2023	Global Solar Atlas (2023)	Tag Image File Format (TIFF)
	Wind energy potential (Wind Speed at 100 m altitude)	2020	Wind Atlas for South Africa (2020)	TIFF
Transport	Primary roads	2009	South African National Roads Agency (The World Bank, 2009)	Shapefile
	Secondary roads	2016	Princeton University Library (2023)	Shapefile
	Sea Ports	N/A	World Port Source (World Port Source, n.d.)[13]	Shapefile

[13] The web page for the World Port Source is no longer active. Data on the ports of South Africa was collected in early 2023 when the web page was still active.

Theme	Dataset(s)	Year last collected/updated	Data sources	Original format
	Airport Runways	2016	Princeton University Library (2023)	Shapefile
	Railroads	2016	Princeton University Library (Princeton University Library, 2023)	Shapefile
Economy	Economic Production for Mining and Quarrying	2018	Census 2011 (Statistics South Africa, 2012)	PDF
	Percentage Workers in Mining and Quarrying	2011	Census 2011 (Statistics South Africa, 2012)	PDF
	Total Mining and Quarrying Workforce	2011	Census 2011 (Statistics South Africa, 2012)	PDF
Social	Dependency Ratio	2022	Census 2022 (Statistics South Africa, 2023)	PDF

Appendix B:

Feedback from Multi-stakeholder Engagement Workshop

Theme	Question(s)	Summary of audience responses
Layout and Experience	What was your experience overall with the Atlas?	The audience were satisfied with the overall layout of the Atlas. Issues pertaining to the maintenance of the tool and gaps in information were raised. The audience also suggested that a user manual be attached to the Atlas.
Information	Do you think the Atlas will provide you with all the necessary information to make informed decisions? What, if anything, do you think is missing?	The audience displayed a consensus that further research is required to incorporate all the necessary information in the Atlas. Local scale information was suggested by numerous audience members, however, it was noted that this information is not readily available – particularly information owned by the Department of Mineral Resources and Energy (DMRE) and mining companies. Issues regarding community expectations of post-closure land use being incorporated in the Atlas was also raised.
Visualisation	On a scale from one to five, with one being the least understood and five being fully understood, how well were you able to understand the visualisations presented in the Atlas?	The average level of understanding of the Atlas was 4.3/5.
	Did you find any of the visualisations of data presented in the Atlas difficult to understand? If so, which ones and why?	Audience members expressed their satisfaction with the visualisation. However, some audience members experienced slow loading of information (although this could be due to individual internet connection speeds). Furthermore, multiple audience members would have liked more time to test the Atlas in a non-abstract manner.
Distribution	The Atlas is web based (i.e., it is hosted via the internet). With this in mind, do you know of any forums or ways to connect with people in communities impacted by mine closure in order to better spread awareness of the Atlas in communities which do have internet access?	The following suggestions were made by the audience regarding spreading awareness of the Atlas: - Community meetings; - Mining company community engagements (including Social and Labour Plan [SLP] engagements); - Training sessions hosted by local NGOs and other organisations; - Local Economic Forums and Community Economic Forums; - At schools; - The Department of Water and Sanitation (DWS) hosts catchment management forums which are open to the public; and - Social media.
	Do you have any suggestions on how we can improve internet access in mining communities to ensure that they can access the Atlas?	The audience emphasised that it is the mining company's responsibility to ensure that mining communities have internet access. Suggestions were also made to work through community centres and NGOs to ensure access to the Atlas.
Further Resources	What else would you like to know and/or do that could potentially be added to the Atlas	The audience suggested that more information should be available regarding agriculture and existing renewable energy potential. Furthermore, more information regarding mining extent and mining licences was suggested to be added to the Atlas. However, it was noted that this information may be difficult to access.
	Can you recommend any resources (books, papers, reports, websites, projects, GIS tools) that the research team should investigate? Or any people we should talk to?	A host of parastatal and other organisations were suggested by the audience. Consultancy firms were also suggested. Emphasis was also placed on expert knowledge that should be incorporated.

Appendix C:
Semi-structured Interview Guiding Questions

Interviews

As part of the development of the South African Mine Closure Risks and Opportunities Atlas (hereinafter referred to as the 'Atlas'), experts were invited to test the Atlas on a mining region of interest to them. They were asked to take note of the layout and the information contained in the Atlas. Lastly, they were asked to use the Atlas to generate a map of their choosing. The map must have illustrated the region of the expert's mining region of interest and any other set(s) of information that they found intriguing.

The questions below were used as guiding questions for a semi-structured interview held after the respective experts were given one hour to test the Atas and produce their maps.

1. **Layout and Experience**
   - 1.1. What was your experience overall with the Atlas?
   - 1.2. Were there any issues regarding navigation to your mining region of interest?
   - 1.3. On a scale of one to five, with one being inaccurate and five being 100% accurate, how accurately was your mining region of interest represented in terms of location in the Atlas?
   - 1.4. On a scale of one to five, with one being least understood and five being completely understood, how well were you able to understand the overall layout of the Atlas? In other words, how well were you able to navigate the various widgets and panels in the Atlas?
2. **Information**
   - 2.1. What information, if any, do you think is still needed to be included in the Atlas to make informed decisions regarding mine closure planning?
3. **Visualisation**
   - 3.1. On a scale from one to five, with one being the least understood and five being fully understood, how well were you able to understand the visualisations presented in the Atlas?
   - 3.2. Did you find any of the visualisations of data presented in the Atlas difficult to understand? If so, which ones and why?
4. **Distribution**
   - 4.1. On a scale of one to five, how likely are you to use the Atlas in your organisation?
5. **Further Resources**
   - 5.1. What else would you like to know and/or do that could potentially be added to the Atlas?
   - 5.2. What kind of analyses, if any, would you like to conduct that is currently not facilitated by the Atlas?
   - 5.3. Is there any information that might be relevant to mine closure in your mining region of interest that is not included in the Atlas?
6. **General comments**
   - 6.1. Is there anything else you would like to say?

Appendix D:
Summary of Interview Responses

Academia	Renewable Energy	Government	Government	Environmental Consulting
Uncertain on how to use most of the widgets in the bottom blue bar.	Operating Mines Layers error on first loading of Atlas	The level of detail contained in the layers are excellent.	Useful to have a consolidated platform which hosts all sources of information	Confusion over the viewing of more than one operating mine at the same time. Requested that a way to view more than one operating mine layer at a time is possible • Suggestion – different symbols/icons for each operating mine layer. • See other GIS tools for inspiration on how to change the icons
Stated that a video tutorial would be ineffective as most people would only view it once.	Emphasis that grid capacity/connection is the most important aspect when considering where to build renewable energy facilities.	Overall layout is clean and easy to understand	Navigation does take some time to get used to	Noted that the Atlas operates similarly to other GIS tools such as Cape Farm Mapper
"What question would make the user need to use the Atlas?"	The Rights to Land information from the Department of Mineral Resources and Energy (DMRE) is the most critical aspect when deciding where to build renewable energy facilities• Land that is in close proximity to the grid is often the right of mining companies • Renewable energy facility developers need to liaise with mining companies to obtain a Section 53 Application (Mineral Petroleum and Resource Development Act) consent to develop on land where mines are located.	There is not enough information contained about socio-economic aspects in the data currently in the Atlas.	Names of mines/communities did not appear sometimes	The Gamsberg Mine is missing (near Black Mountain mine in the Northern Cape)

Academia	Renewable Energy	Government	Government	Environmental Consulting
There is a step missing between clicking on widgets and using the widget to perform a function – perhaps some sort of instruction?	Labels were not clear upon first glance.	It would be useful to include Social and Labour Plans (SLPs) and compliance ratings in the Atlas • Accepted that it would be difficult to include SLPs, but suggested a link to mining company websites for the SLPs.	Colour coding of communities are too similar – confusing	Elevation profile tool is very useful
Widgets should be separated between analytical tools and miscellaneous tools.	Some mines were missing (near Ermelo community)	Information on decommissioning also needs to be included.	User was not aware of the option to change the basemap	Attribute table: • Suggested that selected features be highlighted in the attribute table (See the way that SANBI BGIS does it).
It was difficult to use the data in a sensible way.	The type of mine influences the type of renewable energy development • Good underground geotechnical characteristics are needed • Underground mines create unstable underground conditions which influence above ground developments	Mines are supposed to submit SLPs to SALGA and local municipalities, however it is often the case that mines just don't submit them.	Missing data: • Data related to economic development o Data that may be useful to identify opportunities for post-closure development o Not enough information on economic development o What economic sectors are already active in a particular area? • Map future economic trajectories o This kind of data may be obtained from Local Economic Development Plans or Spatial Development Frameworks. It would be more useful to have it at a provincial level as some local scale municipalities may not have resources to generate this kind of information.	To confirm if kmz can be uploaded to the Atlas via the 'Add Data' widget
	Was not aware of the search function. Suggested that it be a search bar instead of a button	There should be a layer group containing information about economic characteristics.	Widgets – tabular format of information is useful, but it would be better to be able to look at two or more tables are the same time (more than one attribute table) - this will provide more insights	Tailings information useful for baseline descriptions in Environmental Impact Assessments / baseline descriptions

Academia	Renewable Energy	Government	Government	Environmental Consulting
	The Atlas is useful to identify the type of industry to develop in mine closure hotspots, but mining companies need to reskill their workers to work in the renewables/other industries before closure.	Refer to Spatial Tax Data for socio-economic data. o There should be a shapefile for each economic indicator	Would be useful to generate insights based on a particular area. In other words, draw a shape around an area and the Atlas provides information about that area,	The current level of information contained in the Atlas contributes to the strengthening of baseline sections in environmental reporting • Good to understand what is happening around mines. • Gives an idea of cumulative impacts • The information is not limited to the mining industry
			Spatial Economic Activity Data - https://spatialtaxdata.org.za/download-data-landing	Confirmed that the Atlas should be spread within the SRK Environmental departments in South Africa
			NERSA registration data should be in the Atlas.	Would like to see an explanation of the risk ratings • This is to be linked once the broader WRC project is completed
			The user may not trust the source of the data (especially data on mines and communities)	
			I think the biggest take-away from our discussion is the question around how useful the Atlas would be in the hands of potentially 'untrained' users. Although the Atlas is not intended to 'give all the answers', this may well just be the perception of some users. As you say, there are many tools which share information, but not many that provide insights. While it is not impossible to provide some insights, a clear distinction between insights based on 'educated guesses' (i.e., what I, as the developer, thinks) and the actual answers to the questions that users may have (which is not at all intended to be provided by the Atlas).	

Appendix E:
Ethics Clearance

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA · UNIVERSITEIT VAN KAAPSTAD

2023/05/12

EBE/00090/2023

RE: Research Ethics Committee Project Approval Letter

Dear Murad Esau,

Your application for ethics review of your project titled

Developing a National Mine Closure Risk and Opportunities Atlas in GIS for South Africa

has been reviewed and evaluated by the

Engineering & Built Environment Committee.

You may proceed with your research project titled:

Developing a National Mine Closure Risk and Opportunities Atlas in GIS for South Africa

Please note that should:

(i) any serious or adverse effects to participants occur and/or,

(ii) aspect(s) of your current project change and/or

(iii) any unforeseen events that might affect continued ethical acceptability of the project occur then you should immediately report this to the approving REC. You may be required to submit an amendment tothis application, in order to determine whether the changed aspects increase the ethical risks of your project.

Based on the information supplied your application has been successful and is approved.

Please note the following additional conditions associated with this approval:

(i) It is recommended that the researchers consider the time costs for participants to setup free/paid accounts with ArcGIS and its implication on the project and the ability to gather useful feedback during interviews.

Regards,

Engineering & Built Environment Committee.

Appendix F:
User Manual

South African Mine Closure Risk and Opportunity Atlas: User Guide

This document provides guidance on how to use the South African Mine Closure Risk and Opportunity Atlas ("the Atlas"). Note that this guide is for use of the Atlas on a laptop, personal computer and/or desktop only.

1. Start-up and disclaimer

Figure 1: Start-up and disclaimer splash page

When opening the Atlas, a summary of its purpose, what it contains, who is intended to use it and a disclaimer will appear on the screen. Read and understand the disclaimer before clicking “OK” to continue to the Atlas.

2. Atlas overview

There are a number of components embedded into the Atlas to assist users. Table 1 below lists the main widgets and summarises their functionality. Instructions on how to use each widget is explained in the sections below. Figure 2 illustrates the default view of the Atlas which shows all operating mines colour-coded by their likelihood of closure. These widgets/panels are expanded on below.

Table 1: Widgets contained in the Atlas and their function(s)

Widget	Function
Web Map	The web map containing all the relevant data. Users can select features on the map to display more information about them by clicking (laptop/desktop) or tapping (tablet or smartphone) on them. The web map contains an orientation button, default view button (zooms to a default view of South Africa), zoom in/out buttons, basemap button (allows users to choose between various types of basemaps), search button, measure button (allows users to measure distances and areas on the web map), and a full screen button.
Legend Panel	Defines features displayed on the web map

Widget	Function
Layers Panel	A list of all the data contained within the web map. Data is grouped according to themes associated with mine closure risks and post-closure development. Groups can be expanded using the 'expand' arrow on the left of each group. Layers can be hidden or unhidden using the 'eye' icon next to the 'expand' icon. Three horizontal dots on the right of each layer allows users to increase or decrease the transparency of the particular layer. It also provides users with a link to a 'Details' page where more information about the selected layer is given, in addition to a link to the source of the data.
Draw	Allows users to create simple graphics for points, lines, and polygons on the web map.
Elevation Profile	Generates and displays an elevation profile based on a path created by drawing lines on the web map. Slope and elevation statistics can also be viewed.
Print	Allows users to create static maps of the map extent displayed in the web map when the capture widget is selected. A legend, north arrow, and scale bar can optionally be added to the map by configuring the 'advanced' options.
Add Data	Add data sources to the Atlas at run time. Data can be added via ArcGIS content, URL, or local storage (shapefile, csv., or GeoJSON formats).
Location	Allows users to find and analyse features within a specified distance of a selected location.
Coordinates	Displays coordinate values on the map.

Figure 2: Atlas default view

3. Navigating the Atlas

- Left-click and hold anywhere on the map to pan. Right click and hold anywhere on the map to change the map orientation.
- Left-click on the “+” and “-“ in the top left corner of the map to zoom in or out of the map. Alternatively, use the scroll wheel on a mouse to zoom in (scroll up) or out (scroll down).
- The House icon beneath the zooming tool defaults the map view to the whole of South Africa (see Figure 2).
- The Compass located beneath the House icon automatically reorientates the map.

4. Basemaps

The Terrain with Labels basemap is selected as the default basemap. Change the basemap by left-clicking on the Basemap icon in the top right corner of the map and selecting the desired basemap.

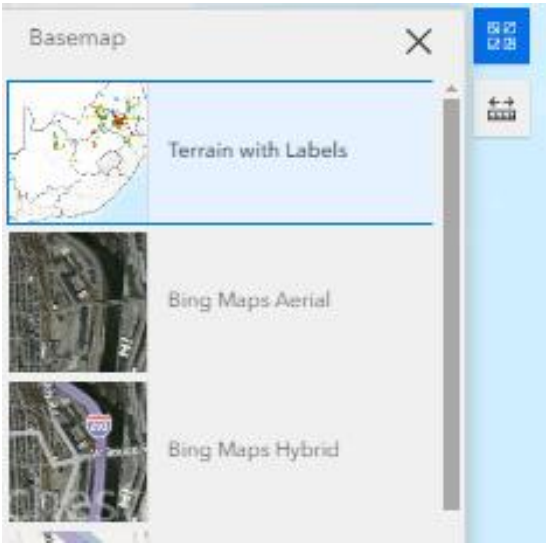


Figure 3: Basemap widget

5. Measure

Left-click on the Measure tool (ruler) button below the Basemap tool button to select the Measure tool.

- To measure a straight line:
  - Left-click on the ruler icon in the Measure tool.
  - Left-click on the desired start point of the line to be measured.
  - Double left-click on the end point of the line to be measured.
  - Select the appropriate metric in the Measure tool.
- To measure area, click on the area icon in the Measure tool.
  - Draw the perimeter of the area to be measured by left-clicking on the desired apexes of the area.
  - Double left-click on the final apex to complete the shape of the perimeter.

- Select the appropriate metric in the Measure tool.

Figure 4: Measure a path

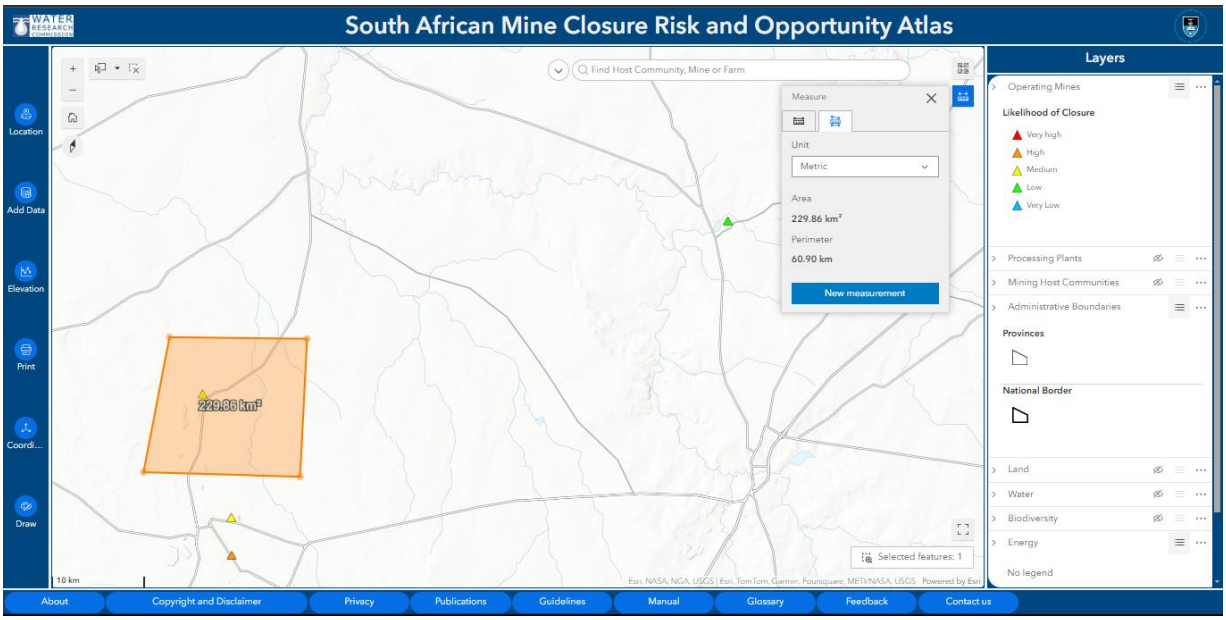


Figure 5: Measure area

6. Layers

The Layers panel is located on the far right side of the Atlas. Data hosted by the Atlas can be found here. Datasets are grouped by theme, and can be turned on/off within their respective groups.

- Left-click on the arrow located on to the left of a group to expand it.
- Left-click on the Visibility icon (eye) to the right of a layer name to activate/deactivate the layer on the map.
- The Legend for a layer will appear below its name when activated.

- Left-click on the three horizontal lines to the right of the Visibility icon to hide/unhide the legend.

- Increase/decrease transparency of a layer by left-clicking on the three dots on the far right of each layer in the Layers panel and selecting “increase transparency” or “decrease transparency”.
- View descriptions/details of data by clicking on the Details icon in the dropdown menu that appears when left-clicking on the three horizontal dots at the far right of a layer.
  - The details page will appear in a new tab within your browser.

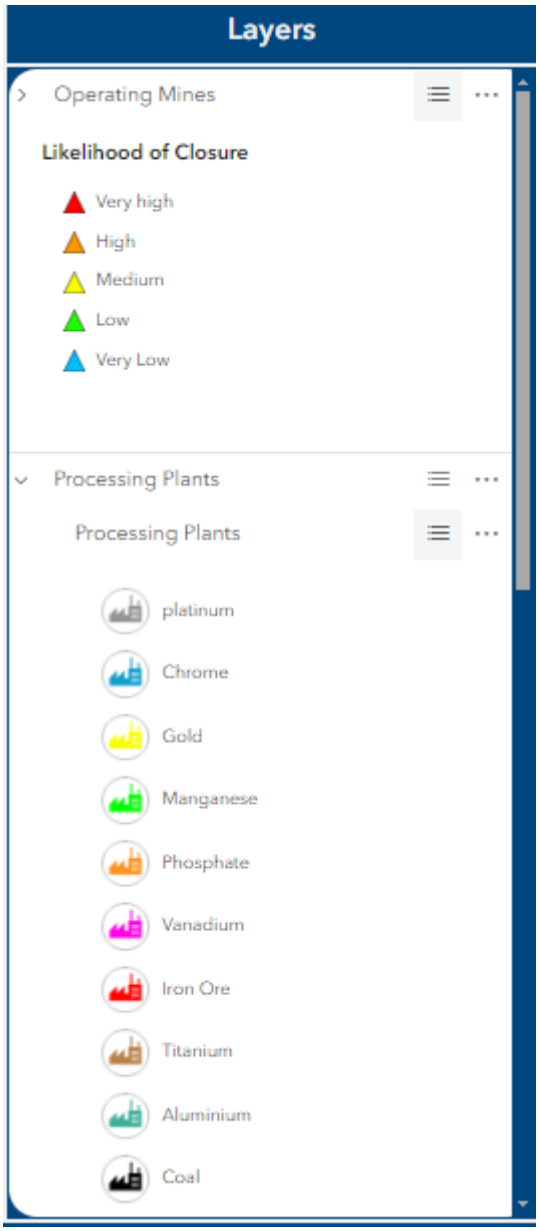


Figure 6: Layers panel

7. Location

The Location widget allows you to find and analyse features within a specified distance of a location. The location can be a:

- Selected feature;
- Drawn graphic; or
- Inserted point location.

The widget can perform three types of analysis:

- Find the feature that is closest to a defined location;
- Find all features within a specified distance of a defined location; and
- Summarize numeric values of nearby features.

To use the Location widget:

- Left-click on the Location widget in the far left panel of the Atlas.
- Select the desired method of identifying a target location (point, line or polygon).
- Select an appropriate buffer distance, if any (this will be the area in which features will be identified in addition to the selected target location)
- A list of identified features will appear in the widget box. Left-click on the desired features to view their respective details.
- Clear your selection by left-clicking on the bin icon in the top right corner of the Location widget window.

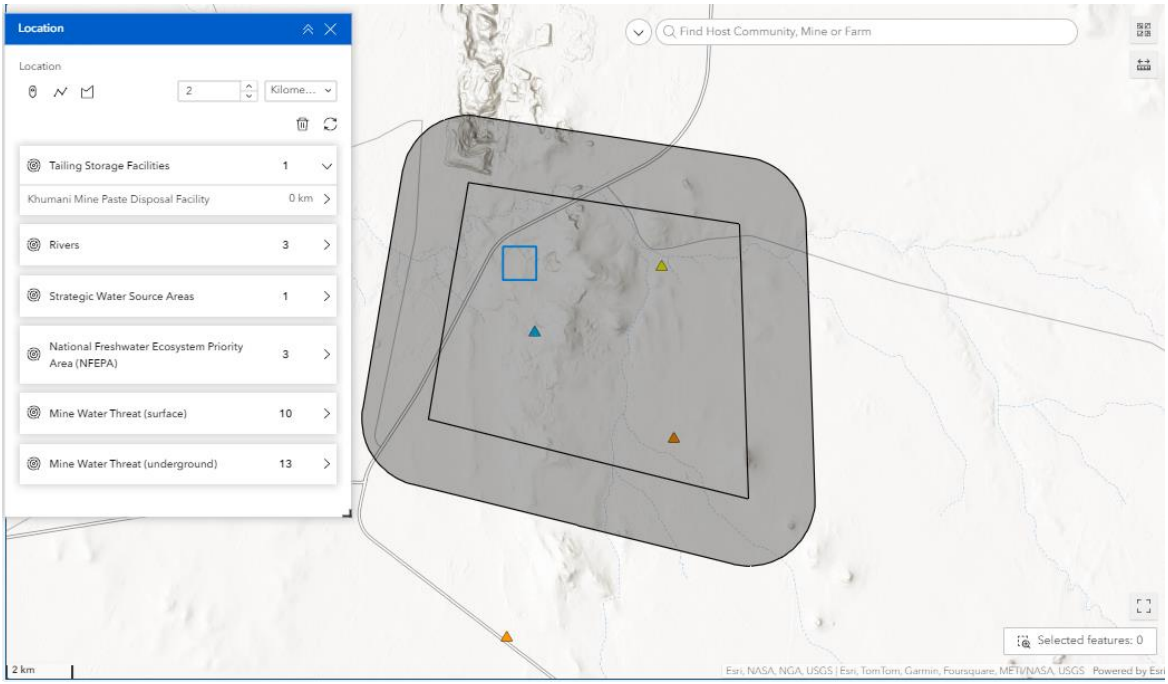


Figure 7: Location widget

The Location widget identifies features within a specified proximity to a target location without the need to view all the layers contained in the Atlas. It should be noted that due to infrastructural constraints, the Location tool is limited to the following datasets that it identifies:

- Tailing storage facilities;
- Mining host communities;

- Former homelands;
- Rivers;
- Strategic water source areas;
- National freshwater ecosystem priority areas;
- Mine water threat (surface);
- Mine water threat (underground);
- Important bird areas;
- National protected area expansion strategy areas; and
- Endangered and critically endangered ecosystems.

8. Add Data

Users can add custom data to the Atlas in the following manner:

- Left-click on the Add Data widget in the far right panel of the Atlas.
- Select the preferred method of adding data. This includes:
  - Data from the ArcGIS server, should the user have an ArcGIS licence;
  - URLs; and
  - Files stored on a user's device.
- File types supported include:
  - Shapefile;
  - CSV;
  - KML,
  - GeoJSON; and
  - GPX.

Note that due to infrastructural constraints, CSV. files are restricted to 1 000 records and all other file types are restricted to 4 000 records. The maximum file size for shapefiles is 2 mb and is 10 mb for all other file types.

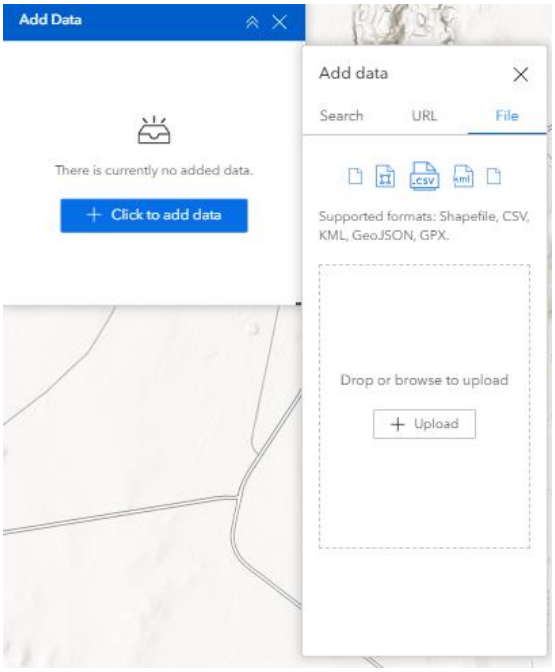


Figure 8: Add data widget window

Note that the custom data added to the Atlas is temporary and will be immediately be deleted from the Atlas once the Atlas is closed in the user's browser.

9. Elevation

The Elevation widget generates and displays an elevation profile based on a path created by drawing lines on the map. Users can view slope and elevation statistics and export the data for each profile. To create an elevation profile:

- Left-click on the Elevation widget in the far left panel of the Atlas. A widget window will open.
- Left-click on the starting point of the desired path on the map.
- Double left-click on the end point of the desired path on the map.
- An elevation profile will automatically be generated and displayed in the widget window.
- Hover the cursor over the elevation profile to view the elevation of specific points.

To view statistics relevant to the elevation profile, left-click on the Ptofile Statistics button in the top right corner of the widget window. A separate widget window displaying the statistics will appear.

To revers the elevation profile, click on the Reverse Direction button in the top right corner of the Elevation Profile widget window.

To export the elevation profile to CSV format:

- Left-click on the Export button in the top right corner of the Elevation Profile widget window.
- Select a custom interval, if desired.
- Left-click on the export button.
- The CSV file will be downloaded to the user's device.

Figure 9: Elevation profile widget

10. Print

To create a map (that can be exported and displayed for other purposes such as reports and presentations):

- Pan to the desired area on the map and make sure the selected datasets are visible.
- Left-click on the Print widget in the far left panel of the Atlas.
- Select a template from the dropdown menu under the "Template" subheading in the Print widget window.
- Type the appropriate map tile under the "Title" subheading in the Print widget window.
- Additional information can be added to the map by left-clicking on the "Advanced" drop down menu.
- Left-click on the Print button at the bottom of the Print widget window.
- The map will be generated and can be viewed under the "Results" tab of the Print widget window (select the tab at the top of the Print widget window).
    - Left-click on the map under the "Results" tab once it is done generating.
    - The map will open in a new tab in the user's browser and can be downloaded from the user's browser.

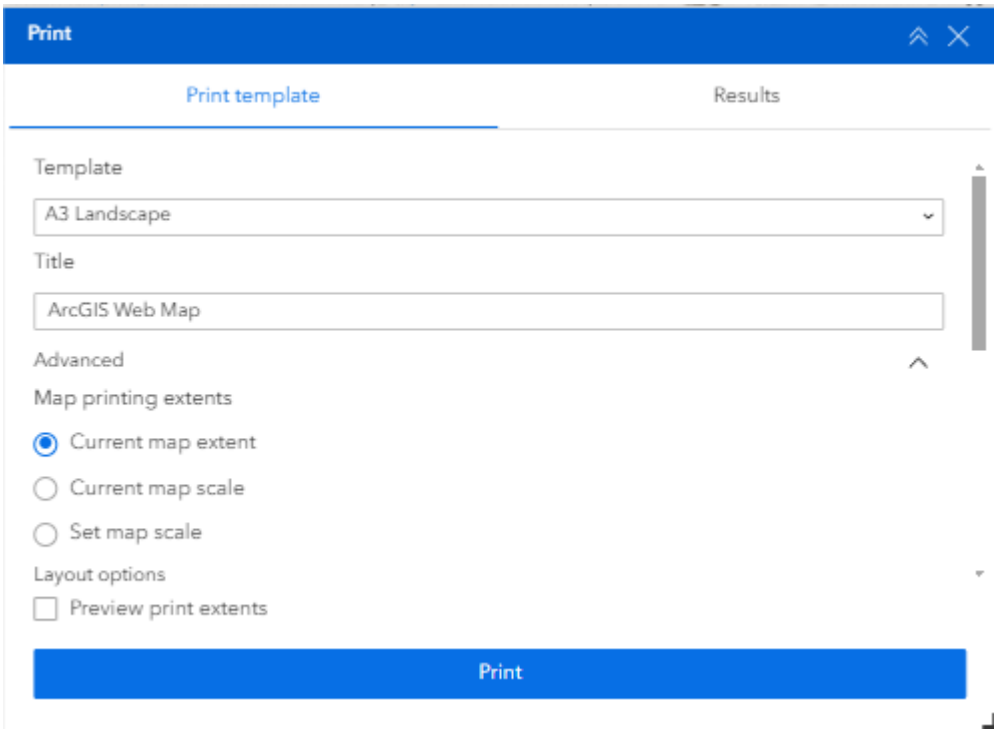


Figure 10: Print widget window

11. Coordinates

To identify the coordinates of a specific location on the map:

- Left-click on the Coordinates widget in the far left panel of the Atlas. A widget window will appear.
- Hover the cursor of a desired location on the map. The coordinates of that location will appear in the Coordinates widget window.

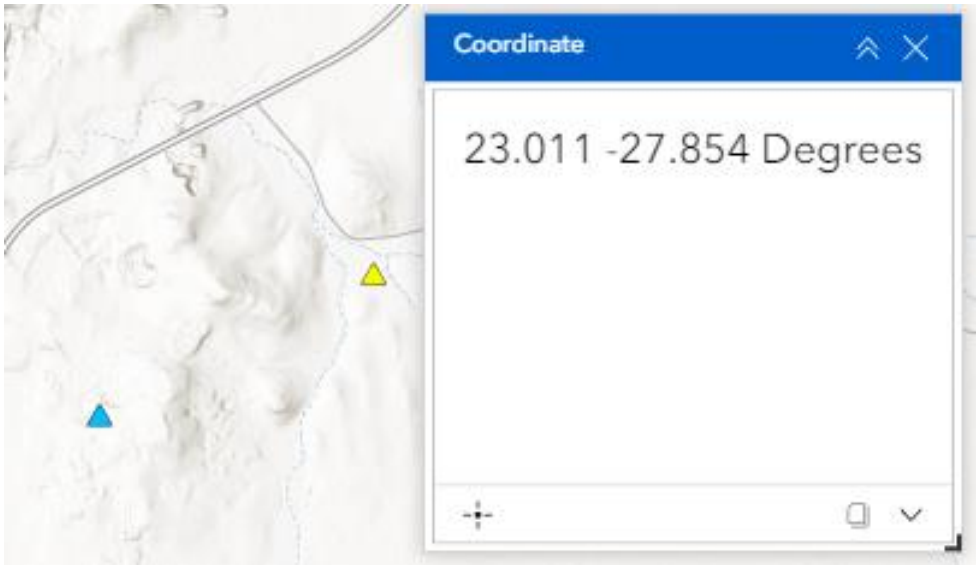


Figure 11: Coordinates widget window

12. Draw

The Draw widget allows users to create simple graphics for points, lines, and polygons on the map. To create a graphic:

- Left-click on the Draw widget in the far left panel of the Atlas A widget window will appear.
- Select the method in which to draw the graphic (point, line polygon, rectangle or circle) from the top of the widget window.
- Draw the graphic.
- Customise the graphic by left-clicking on the button in the far right corner of the widget window and selecting a colour for the graphic.
    - Measurements (perimeter and area of the drawn graphic) can also be configured to be show from this button.
- Clear the graphic from the map by left-clicking on the Clear button in the top right corner of the widget window.

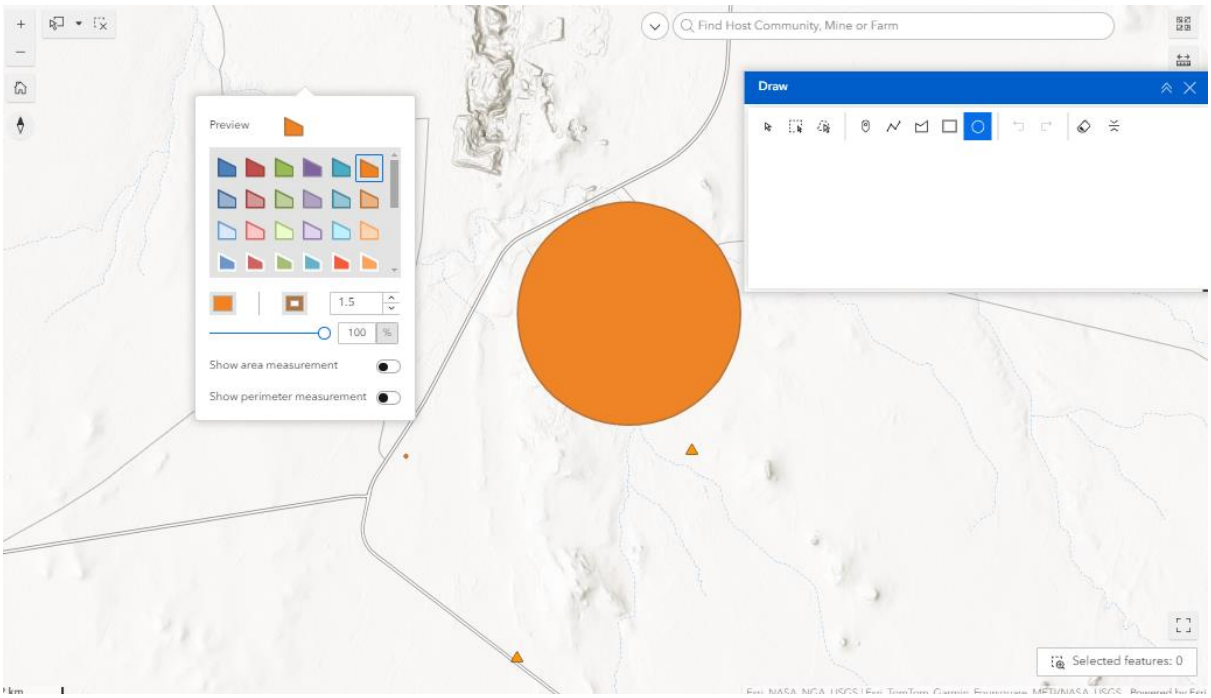


Figure 12: Draw widget window and example graphic

13. Search

To search for mining host communities, operating mines, and/or cadastral farms:

- Left-click on the search bar at the top right of the map.
- Type the name of the desired mining host community, operating mine or cadastral farm.
- Select the identified mining host community, operating mine or cadastral farm from the dropdown list. It will be highlighted on the map.

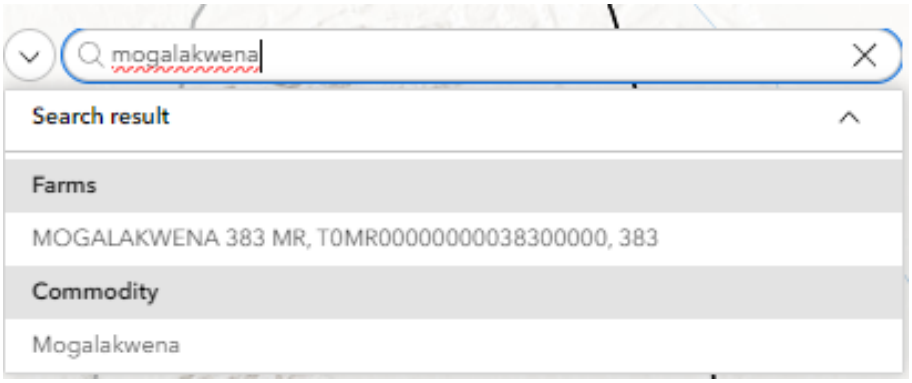


Figure 13: Search tool

14. Pop ups

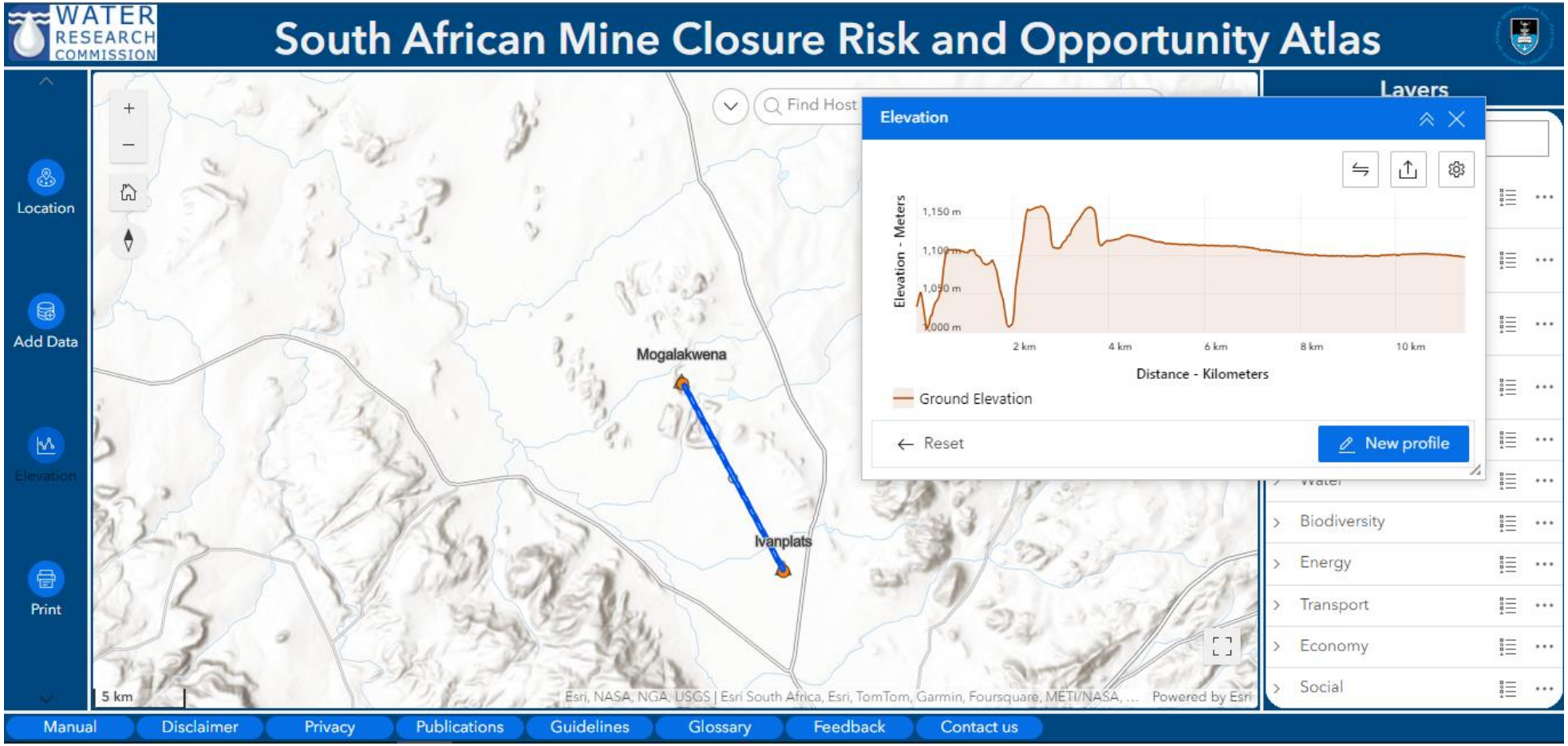
Pop-ups display information about map features within the Atlas. They can be viewed by left-clicking on the desired map feature.

Figure 14: Pop-up displaying information related to a mining host community

Appendix G:
Examples of Widget Functionality

Polygon drawn over a Tailings Storage Facility and Kusasalethu Mine

Coordinates of South Deep Mine



Elevation profile between Mogalakwena and Ivanplats Mines