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Developing a national mine closure risk and opportunity atlas for South Africa

M Esau *University of Cape Town, South Africa*

MJ Cole *University of Cape Town, South Africa*

JL Broadhurst *University of Cape Town, South Africa*

T Chimbganda *University of Cape Town, South Africa*

A Abrams *University of Cape Town, South Africa*

Abstract

Mining is deeply embedded in the history of modern South Africa and has played a major role in the country's geopolitical and socio-economic development. It continues to be a critical contributor to the national economy (7.5% of GDP) and the world's supply of metals and minerals, producing 74% of global platinum, 36% of chrome ore, 36% of manganese, 23% of zirconium, 8% of diamonds, 3.5% of gold and 3.2% of coal. There are currently 202 operating large-scale mines owned by 90 mining companies and hosted by 325 urban and rural communities across South Africa, home to 6.5 million people. Many of these communities are dependent on mining for jobs and local business, and they will be significantly affected by mine closure.

Mine closure risks and land-use opportunities are site-specific, and affected by numerous social, economic, environmental, governance and infrastructural factors, and policies and practices need to take them all into account. National government and other stakeholders need guidance in terms of identifying high risk areas, relevant policy interventions and suitable post-closure land-use opportunities. This paper describes one aspect of a 3-year research project aimed at producing mine closure risk ratings for every large-scale mine and a post-closure land use opportunity framework to inform and support mine closure planning. A South African Mine Closure Risk and Opportunity Atlas has been developed using ArcGIS and QGIS software as a publicly available online tool. It shows the locations and key characteristics of all mines and communities, preliminary risk ratings for likelihood of closure, social impact and environmental impact, as well as their underlying data so that the user can make their own assessment. Post-closure land use opportunities can be analysed based on diverse datasets pertaining to communities, municipalities, land, water, energy, biodiversity and infrastructure by users of the Atlas as part of a bigger analytical process.

The Atlas adds value through its diversity and comprehensiveness with 52 nation-wide datasets displayed, its functionality allowing users to perform typical GIS-type tasks, and its accessibility to all stakeholders as it is designed for computers and smartphones. It has been tested with experts from civil society, academia, consulting, mining companies and government and applied to case studies of post-mining land-use in platinum, gold and coal mining areas. While it has been developed for South Africa, the concept, design and insights could be applied to any mining country in the world.

Keywords: *GIS, web mapping, mine closure, post-closure land use, risk ranking*

1 Introduction

1.1 Mining in South Africa

Mining is deeply embedded in the history of modern South Africa and has played a major role in the country's geopolitical and socio-economic development (Cole & Broadhurst, 2020). Although the contribution of mining to the country's GDP has declined since its peak in 1980, it continues to be a critical contributor to the national economy (7.5% of GDP) and the world's supply of critical resources, producing 74% of global platinum, 38% of palladium, 36% of chrome ore, 36% of manganese, 34% of vermiculite, 23% of zirconium, 5% of fluorspar and 3.5% of gold (USGS, 2023), 8% of diamonds (SADPMR, 2022) and 3.2% of global coal (BP, 2022). In 2022, the mining industry employed 475,561 people, the majority of whom work in platinum (36%), gold (20%) and coal (19%) mines (Minerals Council South Africa, 2023). A total of 18 major commodities are currently produced in 203 mines, operated by 90 mining companies (Cole & Broadhurst, 2021). These operations are supported or hosted by 227 diverse communities, including cities, towns, townships, mine villages, and rural villages, across South Africa (Figure 1), home to about 6.5 million people. The biggest populations are found in coal (38%), platinum and chromium (34%), gold (24%) and diamond (7%) mining areas.

Historically, the benefits of this mineral wealth have not been shared equitably and the lack of adequate legislation and poor industry practices have left a legacy of abandoned mines, degraded land and polluted environments, with concomitant effects on the health, quality of life and livelihoods of local communities (Krause & Snyman, 2014). The management of public health and safety impacts and environmental impacts on water and air quality of abandoned, derelict, and ownerless mines has become a significant burden to the government (Marais & Nel, 2016; Watson and Olalde, 2019), particularly the Witwatersrand goldfields, the Kwazulu-Natal coalfields and asbestos mines which are the focus of national government rehabilitation efforts (Auditor-General of South Africa, 2009). Although mining companies are required to set aside financial provisions for rehabilitation, this is a relatively new requirement and the general perception is that government and industry are failing in their efforts to address the negative environmental legacies of mining in South Africa (IHRC, 2016; SAHRC, 2016, Sefatsa & Horsfield, 2022), and to provide the anticipated socio-economic benefits to mining host communities (Bruechner et al., 2021; Marais et al., 2021).

1.2 Mine closure risk and opportunities

Considerable concern also exists around the potential impacts of on-going and future mine closures over the next few decades (Brock, 2021), particularly for gold and coal mines, however mining companies can make a significant positive contribution to their local communities through good closure planning (ICMM, 2019). In other regions within South Africa, the increased global demand for 'energy transition minerals', such as platinum, iron ore, manganese, copper and vanadium, which are all crucial to emerging green energy and e-mobility technologies, may precipitate a resurgence of mining activity. The mine closure process is complex, and establishing sustainable post-mining land-uses and social transitions continue to be a global challenge (Kabir et al., 2015; McCullough, 2016; Bainton & Holcombe, 2018; Fawcett & Laurencont, 2019). It is critical that mine closure planning considers both the environmental and the socio-economic impacts and includes rehabilitation and economic diversification and succession planning (Bainton & Holcombe, 2018; Edwards & Maritz, 2019; Marais & Nel, 2016; IRMA, 2018; ICMM, 2019; World Bank, 2021; Limpitlaw & Briel, 2014). Risk assessment, involving the identification of hazards and estimating their likelihood and impact, and its application to mine closure have become increasingly important in mine planning (Government of Western Australia, 2020; ICMM, 2019). Across mine closure guidelines there is consensus that effective data collection ensures that risks are managed and monitored (Coppin, 2013; Kabir et al., 2015; Manero et al., 2020) although the emphasis continues to be on environmental indicators (Bainton & Holcombe, 2018; Beckett et al., 2020). Mine closure and post-closure risks and opportunities are site and community specific, with mine downscaling and closure affecting different communities to varying degrees and in distinctive ways, depending on factors such as the mine's contribution to the local economy, the living standards and employment levels of communities, and the capacity of the local government to facilitate a transition away from mining. Given these complexities, the government and other stakeholders need support in identifying mines that are likely to close soon and those that have high potential impacts to host communities and the natural environment. Post-closure land use interventions should be selected based on a rigorous assessment of all social, economic and environmental influencing factors and all possible options.

1.3 GIS in mining

All operations in GIS are done with the utilisation of geographically referenced data (Harris & Weiner 1998). Geographic Information Systems (GIS) are conventionally used in the mining industry during the exploration phase of a mine, for the development of Environmental Impact Assessments (EIAs), and for mine management (Werner et al., 2019). However, GIS can also be used 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; manage land titles; process closure; identify suitable reclamation activities; and improve community education (Esri, 2018). 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). Furthermore, the use of GIS supports the International Council on Mining and Metals (ICMM) Conservation of Biodiversity principle by aiding the assessment of risks and impacts to biodiversity and ecosystem services, which paves the way for identifying methods of implementing the mitigation hierarchy to achieve no-net-loss of biodiversity (ICMM, 2023). The importance of GIS in mining is evident in the growing number of GIS-based assessments of mining and datasets related to mining (Luckeneder et al., 2021, Maus et al., 2022, Tang & Werner, 2023, Geoscience Australia, 2023).

This paper describes the development and application of a novel Mine Closure Risk and Opportunities Atlas for South Africa, an ArcGIS web map which displays mining, social, economic, environmental, governance and demographic datasets that are relevant to mine closure. Section 2 details the methodology which describes the development of the tool in ArcGIS Pro, the identification of stakeholders and the process of obtaining expert input. Section 3 provides details on the data found in the Atlas, section 4 shows the results through the functionality of the Atlas, the preliminary risk maps, expert inputs and case studies. Section 5 discusses the use of GIS in the mining sector, the challenges and opportunities around data, and the importance of making information on mine closure available to all stakeholders.

2 Methodology

The Atlas was developed based on the premise of the concept of a 'Creative Technologies' (CT) design process, which aims 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). Thus, an iterative approach was undertaken to develop the Atlas.

2.1 Quantitative data collection and processing

Spatial, demographic and socio-economic data on all South African mines, mining communities and local municipalities previously collated by some of the project team (Cole & Broadhurst, 2021, 2022; Cole et al., 2023a) were used and expanded using the Census 2011 database and Community Survey 2016 database in SuperCross made available by DataFirst (StatsSA, 2014; StatsSA, 2017). Open-source quantitative data in various formats were collected from various national and international sources, such as the South African National Biodiversity Institute (SANBI), the national Department of Water and Sanitation (DWS), the BirdLife International Programme and the South African Department of Forestry, Fisheries, and the Environment (DFFE), the South African National Roads Agency (SANRAL), and the South African Environmental Observation Network (SAEON) (see Table 1) and converted into a consistent format and georeferenced.

The risk ratings were developed based on available quantitative datasets and previous research, and tested with experts (Cole et al., 2023b). They record likelihood of closure based on five weighted indicators (life of mine, mineral reserves, commodity markets, mining method, company type), environmental risk based on nine weighted indicators (mining duration, distance to endangered ecosystems and protected areas, distance to strategic water source areas, mine water threat, land capability, tailings dam failure risk) and social risk based on seven weighted indicators (population, community type, social vulnerability, direct mining jobs, local economy dependence, remoteness and government capacity). They are described in detail in a separate paper (ibid). The risk ratings and their individual data sources are stored in the Atlas so that the user can make their own risk assessment. The post-closure land use opportunities are meant to be reviewed and assessed by users of the Atlas as part of a bigger analytical process.

Table 1 Datasets in the South African Mine Closure Risk and Opportunity Atlas

Theme	Datasets	Data sources
Mines	operating mines, mine site boundaries and features, tailings facilities	Cole & Broadhurst 2021, Tang & Werner 2023, Maus et al. 2022, Global Tailings Portal 2023
Communities	mining communities, local municipalities, main places, sub places	Cole & Broadhurst 2021, StatsSA census spatial data
Administrative boundaries	provinces, district municipalities, local municipalities, farms, former homelands	Municipal demarcation board spatial knowledge hub
Water	strategic water source areas, mean annual runoff, mean annual rainfall, mine water threat, drinking water quality, wastewater quality, water stress, rivers, dams, estuaries	SANBI biodiversity GIS, DWS spatial data, WRC Mine Water Atlas, DWS Green Drop Report 2023, DWS Blue Drop Report 2023, Cole et al. 2018
Land	land capability, land cover, morphology, grazing capacity	DAFF, South African DFFE GIS Data, Kruger 1983, SANBI biodiversity GIS
Biodiversity	ecosystem threat status, protected areas, conservation areas, important bird areas, mining and biodiversity guidelines, protected areas expansion strategy focus areas, national freshwater ecosystem priority areas	SANBI biodiversity GIS, BirdLife South Africa
Energy	power lines, existing power plants (coal, solar, wind, nuclear, hydro), EIA Applications for renewable energy development, renewable energy development zones, strategic transmission corridors, strategic gas pipeline corridor, solar energy potential, wind energy potential	DFFE GIS data, Global Energy Monitor, Wind atlas for South Africa, Global Solar Atlas
Transport	primary road, secondary roads, ports, airports	SANRAL, World Port Source

Quantitative data were 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 spatial data. The quantitative data was uploaded to ArcGIS Online – a web-based mapping software developed by Esri – and compiled into an ArcGIS web map i.e. a display of geographic information that can be interacted with in various ways (Esri, 2023). The data was then studied to identify and understand the types of functionalities required for the Atlas.

2.2 Development of the user interface

The web map was inserted onto a user interface and multiple iterations of the user interface were developed using ArcGIS Instant Apps, which provides templates for developers to display georeferenced information, and ArcGIS Experience Builder, a platform that enables developers to create highly configurable web applications without requiring knowledge of computer programming/coding more flexible solution for developing web map applications such as the Atlas (Esri, 2023). ArcGIS Experience Builder allows developers to embed web maps in a layout of their choice without restriction. Developers 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. It does require users to access it through their internet browser. The Beta 1.0 version of the Atlas was developed using ArcGIS Instant Apps 'Exhibit' template. The Beta 2.0 and current versions were developed using ArcGIS Experience Builder.

The Atlas was designed to be comprehensible by stakeholders with various backgrounds and co-development of software requires careful consideration of the intended users of the Atlas. Table 2 illustrates potential users of the Atlas by adapting the key stakeholders of mine closure planning identified by the ICMM (ICMM, 2019) to the South African context. Government officials 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. Since all the data reproduced in the Atlas is open-source, users can download the data directly from the Atlas to be used in other databases. For example, consulting firms will be able to download data from the Atlas for development of their own databases.

2.3 User testing and stakeholders

The Beta 1.0 version was presented to the project reference group (comprising eight academics and industry experts) to gauge expert opinion while the Beta 2.0 version was presented at an online stakeholder engagement workshop conducted by the Project Team on 6 March 2023 via Zoom. Over 70 experts in the mining industry, consulting, academia, civil society, and government, were invited however only 15 attended on the day. The project team presented the draft mine closure risk framework and the Beta 2.0 version of the Atlas. The draft risk rating and the Atlas's functionality were presented to the workshop participants before a live link to the Atlas was shared with them. Participants were given approximately 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 and each theme comprised of one or two questions – a limit imposed by Zoom Advanced Polls. The stakeholder feedback was used to develop the Beta 3.0 version of the Atlas.

2.4 Case studies

Three large-scale operating mines in different mining regions were considered for the purpose of testing the process of using the Atlas. The Atlas, through observations and analyses of its datasets, was used to assess potential risks of mine closure and potential post-closure land use developments for the three mine sites. The mines were selected based on a variety of characteristics, namely the commodity, mining company, number of mine employees, mining method, life of mine and geographic location.

Table 2 Stakeholders considered as potential users of the Atlas

Stakeholder	Potential use of the Atlas	Scale of information	Frequency
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	Planning, risk assessments	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
Media	Raising awareness	All scales	Ad hoc
Researchers	Conduct research that informs mine closure policy and planning	All scales	Ad hoc

3 Data

The Atlas displays 44 national datasets and eight global datasets obtained from multiple sources, together with the project team's own research, which are listed in Table 1 above. The primary datasets are the 202 large-scale operating mines and 325 mining host communities which have been developed over the past five years. Data included in the operating mines dataset covers commodity, company, life of mine, mining method, duration of mining, employees and the three risk ratings. A third of all operating mines are coal mines and over a quarter are platinum mines. The mines are hosted by very diverse communities, which include cities, mining towns, non-mining towns, townships, mine villages, informal settlements, and rural villages. They were home to almost 6.5 million people in 2011 and are situated in three metropolitan municipalities and 58 local municipalities that had a total population of 23.6 million in 2016. Data included in the community dataset covers main commodity, type of community, municipalities, area, population, households, population density, household size, gender, race, urban/rural, collective living quarters, industrial areas, formal housing, household income, household goods, health (disability), education level, piped water access, electricity access, cooking fuel, refuse removal, employment, and internet access. All datasets in the Atlas can be overlayed on various base layers built into the Atlas, including base layers of satellite imagery, which assist the analyses of mine sites. Other base layers include topographic, terrain and open street maps.

4 Results

4.1 Atlas functionality

The South African National Mine Closure Risk and Opportunity 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. Upon opening the Atlas, users are greeted by a splash page which welcomes them and provides a brief description of the Atlas, the data it contains, its purpose, and the target audience. The main map then appears with all mines and mining communities displayed on a satellite map of South Africa (Figure 1). A Layers panel on the right gives the user access to all the datasets which are categorised under nine headings – Mine Locations, Communities near Operating Mines, Administrative Boundaries, Mine Site Features, Land Use, Water, Biodiversity, Energy and Transport. Each category has a dropdown list of all the relevant datasets which can be displayed on the main map and toggled on or off as required. A 'Details' page is linked to every dataset, which opens in a new tab and provides a brief overview of the dataset and a direct link to its source. A Legend panel on the left shows the legends for the current active layers. The default display is of mines colour-coded by their likelihood of closure risk rating (Figure 1), but other legends (e.g. commodity, social impact of closure risk rating, environmental impacts of closure risk rating) can be shown. These risk ratings were determined quantitatively using numerous indicators and weightings and are described in another working paper.

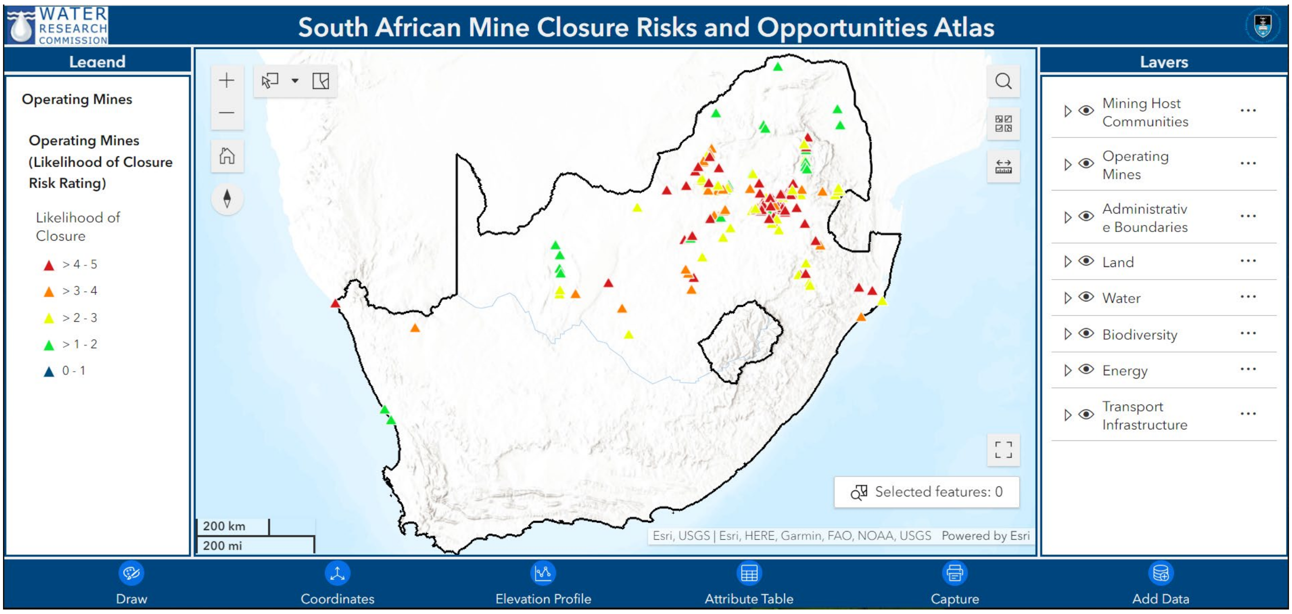
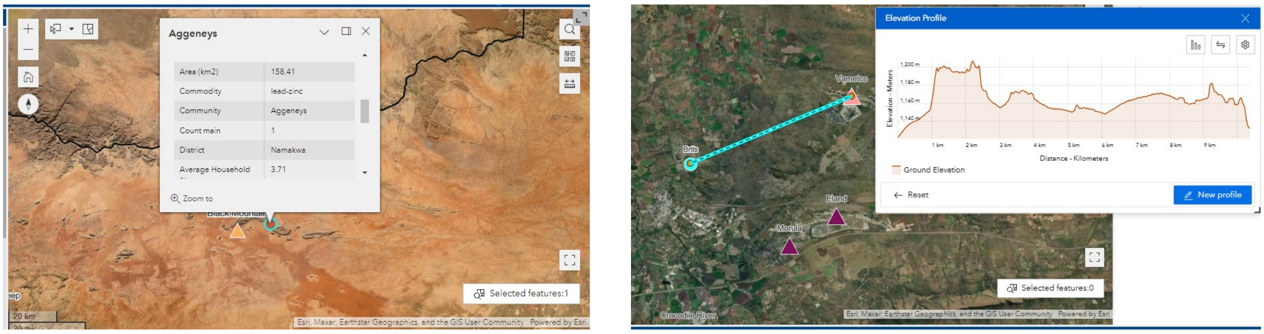


Figure 1 Screenshot of the default page for the South African Mine Closure Risk and Opportunity Atlas, which displays the mines (triangles) coloured by likelihood of closure rating

Discrete data pertaining to individual mining host communities and mines can be accessed by selecting the mining host community or mine of interest from the map and are presented using pop-ups (Figure 2a). Built-in interactive tools allow users to search for a particular location on the map by typing in key words or the name, zoom in or out, toggle spatial layers on or off, and change the base map. Widgets have been added to the Atlas to enable users to draw graphics, add their own data, plot elevation (Figure 2b), and capture and download static maps as described in Table 3. While the Atlas works best on a desktop or laptop, it has also been calibrated to work on smartphones and tablets accessed by users can through a browser on their device. When using the Atlas on a tablet or smartphone, navigation is not as sophisticated as when used on a desktop or laptop as some functions may not work, however all the same datasets are present.



(a) (b)

Figure 2 Screenshots of (a) a data pop-up for a mining community and (b) an elevation profile

Table 3 Widgets contained in the Atlas and their function

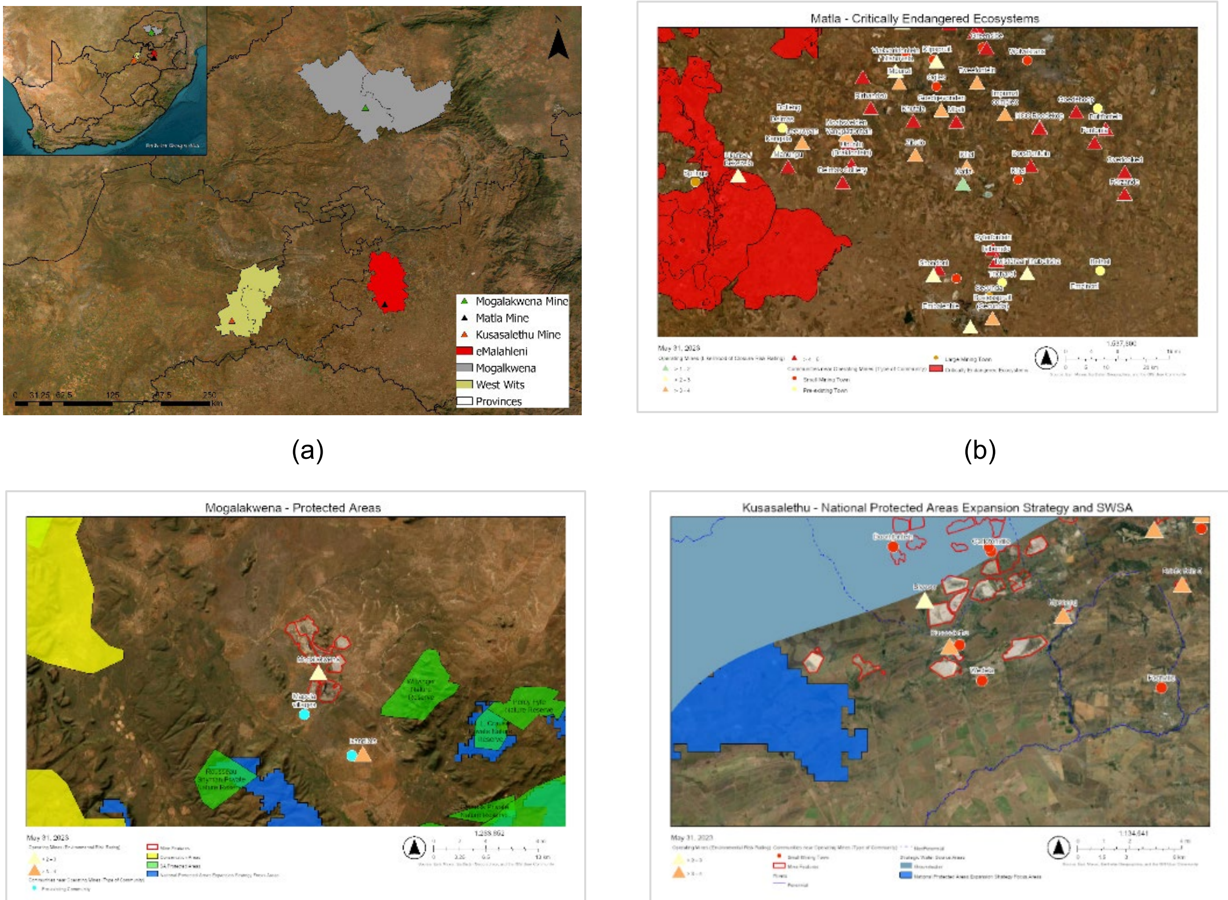
Widget	Function
Web map	Contains all the data. Users can select features to display more information about them by clicking (laptop/desktop) or tapping (tablet or smartphone) on them. Contains orientation button, default view button (zooms to a default view of South Africa), zoom in/out buttons, base map button (choose between base maps), search button, measure button (measure distances and areas on web map), and a full screen button.
Legend panel	Defines features displayed on the web map.
Layers panel	Lists all data in the web map grouped by theme. 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 layer and provides a link to a ‘Details’ page with metadata.
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 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 using the ‘show/hide’ icon. Attribute tables can be downloaded in csv format.
Capture	Allows users to create static maps of the map extent displayed when the capture widget is selected. A legend, north arrow, and scale bar can be added in ‘advanced’ options.
Add data	Adds data sources to the Atlas at run time via ArcGIS content, URL, or local storage (shapefile, csv, or GeoJSON formats).

4.2 Expert input

Based on the responses at the online multi-stakeholder engagement workshop, 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 were raised pertaining to the information in the Atlas. These issues mainly pertain to the lack of local scale information regarding mine closure. 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. The research group are aware of this aspect and plan to conduct individual interviews with relevant experts in the following phases of the research programme (audience members from this workshop were also invited to take part in these interviews). Lastly, the audience provided valuable information regarding the distribution of the Atlas and further resources that will be of use for its further development.

4.3 Case studies

The mines selected for case studies are Harmony's Kusasalethu underground gold mine in Gauteng province, Exxaro's Matla underground coal mine in Mpumalanga province and Anglo American's Mogalakwena open pit platinum mine in Limpopo province. They are owned by international mining companies and have closure plans, although they are in very different stages; their life of mine varies from 1 year (Kusasalethu) to 76 years (Mogalakwena) and Matla has a proposed expansion project. Figure 3 illustrates the case study locations and three maps produced using the Atlas which display operating mines (coloured by likelihood of closure), mining communities (coloured by type), and mine site features (red outlines), together with different datasets related to environmental risk. Map B shows critically endangered ecosystems (red) around Matla mine. Maps C shows the Protected Areas (green) and Conservation Areas (yellow) around the Mogalakwena mine. Map D illustrates Strategic Water Source Areas (light blue) and National Protected Area Expansion Strategy areas (dark blue) around Kusasalethu mine.



(a) (b)

(c) (d)

Figure 3 Case studies locations (a) and example maps generated in the Atlas (b-d)

5 Discussion

5.1 Value of a GIS-based mine closure atlas for the mining sector

The Mine Closure Atlas presented in this paper was designed to facilitate mine closure risk assessment and post-closure land use development planning related to the South African mining industry. Although stakeholders have access to much of the information contained in the Atlas, they may not be aware of it, and there is no single platform which makes integrates the diverse datasets and makes them easily accessible. The comprehensive array of datasets in the Atlas adds value to the mining sector by providing access to information from a centralised node connected to segregated information sources. Additionally, the Atlas facilitates advanced analyses, such as plotting elevation profiles, from within the Atlas without requiring the downloading of specialised software.

The Atlas displays mining, social, economic, environmental, governance and demographic datasets that are relevant to mine closure. The intention of the Atlas is threefold: 1) to make data and information of mines and mining communities and their associated risks and opportunities publicly available to all stakeholders, 2) to provide a visual comparison of likelihood of mine closure, socio-economic risk and environmental risks for all operating mines, and 3) to provide an analytical tool to assess mine closure risks and post-closure land use opportunities by making multiple relevant spatial datasets accessible and user-friendly. These aspects support mine closure planning and aid decision-making processes at all scales. While the Atlas offers a preliminary risk rating for each mine site, the underlying data is also included so that the user can make their own assessment. The post-closure land use opportunities are meant to be reviewed and assessed by users of the Atlas as part of a bigger analytical process. Analyses such as environmental risk analyses using a GIS database – as illustrated by Werner (2019) who conducted a preliminary comparative environmental risk analyses on four abandoned mines in Australia using satellite imagery and geospatial information – is intended to be conducted by users of the Atlas rather than the Atlas presenting a set of answers. Instead, the Atlas is presented as a facilitator for such analyses.

The environmental, social, economic, infrastructural and governance datasets presented in the Atlas support evidence-based decision-making on post-closure land use by bringing together diverse spatial datasets together with mine site information. For example, the potential for agriculture can be assessed with the water supply, land cover, land capability and grazing capacity datasets before this is put forward as an option; solar potential, wind potential and electricity transmission lines datasets can be reviewed together before renewable energy generation is proposed; and water stress, local education levels, governance metrics and road networks can be reviewed together when considering starting new industries.

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 supports communities impacted by mining who are least represented (Werner et al. 2019). Making information about mine closure risks and opportunities accessible to mining host communities, particularly through the Atlas being supported on smartphones, empowers them to engage in and influence decision-making processes. Showing the evidence for socio-economic deprivation in mining host communities to mining companies gives them the understanding and motivation to do more to support these communities when mine closure occurs. This is effective use of GIS in the context of socio-economic dynamics – empowering the least represented to participate in decision-making processes (ibid).

5.2 Data challenges and opportunities

Datasets contained in the Atlas were collected during 2022 and 2023. While every effort has been made to incorporate the most recent and up to date data, the Atlas will require updates over time as new mines open and existing mines close, existing datasets are updated and new datasets are released. This requires a dedicated website, ArcGIS licence, and a person or team who stays abreast of developments, and thus ideally should be institutionalised. The Atlas currently presents a snapshot of information although it has an 'Add Data' function, which allows users to insert their own spatial data into the Atlas and combine it with the other datasets. In future additional functionality could be added to display time series data for certain datasets. While the maintenance of the Atlas could be seen as the responsibility of the national government, current failures in maintaining other datasets and platforms (e.g. the national mining cadastral system) make this unviable at this time.

While there are many national open-source datasets available online that are useful for assessing mine closure risks and post-closure land use opportunities, as shown in Table 1, some are not regularly updated. One example is the community-level socio-economic data obtained from the national census which is undertaken once every 10 years. StatsSA performs the household surveys but is financially constrained; however, the mining industry could provide financial support and benefit from a better understanding of their host communities.

It would be very useful to have local mine site technical information. Most mining companies report environmental data (such as water use) at the corporate level, aggregating all mine sites for a region, country or company. Mine site expansions are not generally publicised until they have been through the required environmental impact assessments and approvals and as such cannot be independently assessed by civil society and communities who will be most affected. Several stakeholders emphasised the need for mine site information but agreed that this is difficult to obtain mining companies are not required to make the data publicly available and they typically do not want to release data without it being interpreted. The national

DMRE is the responsible authority which facilitates the sharing of this information, however, they often fail to do so.

Additional datasets that would be helpful in assessing mine closure impacts and planning for closure include financial provisions; current land ownership and zoning; land claims by traditional authorities and dispossessed people; historical land use, historical mine design and site configuration including underground mine maps to understand the impact on water resources, and surface maps to assess site human and ecological risks.

5.3 Data access and interpretation

In addition to issues of internet access in South African mining host communities, awareness of the Atlas and the data it contains is a key factor in mining host community participation in decision-making processes regarding mine closure planning. Stakeholders suggested several solutions for awareness creation within local communities. While all these solutions are viable, they all require third party endorsement. Since the data contained within the Atlas can potentially be interpreted as detrimental towards the perception of certain mining companies, they may be hesitant to make their stakeholders aware of it. Therefore, a third party that is concerned with the wellbeing of the environment and society without financial influence is best suited to facilitate awareness campaigns for the Atlas. This includes governments and NGOs, who can assist in awareness creation of the Atlas at local community meetings, local economic forums and community forums, schools, and sharing the Atlas on social media. NGOs and other organisations may host training sessions on the Atlas.

Once stakeholders are aware of the Atlas, it is imperative that they are educated on how to interpret the data contained in the Atlas. The Atlas was designed with a simple user interfaced that does not require any specialised training to use. However, the low levels of basic education among South African mining host communities (Cole & Broadhurst, 2021) may pose an obstacle to these stakeholders. While interpretation is a subjective exercise, understanding the implications and nature of data in the first instance is the first critical step in the process of interpretation. The Atlas provides metadata and details about each dataset it contains via the Details page to support this, however, it is difficult to determine the level of understanding and interpretation of the data by potential users. Some responsibility lies with mining companies to translate complexity into simple easy to understand language for their affected parties to understand when dealing with mine closure. While that takes time and resources, it could have significant benefits of positive stakeholder relations and a higher likelihood of success of post closure initiatives.

6 Conclusion

This paper has described the development of a novel GIS-based tool to inform a wide range of stakeholders about mine closure risk and opportunities and support assessment of these risks and opportunities in South Africa. It is hoped that the Atlas will promote deeper discussions on mine closure management and planning amongst a diverse group of stakeholders, and support evidence-based decision-making. The comprehensive spatial database covering mines, waste facilities, communities, land, water, energy, biodiversity, infrastructure and governance will be publicly available to support just economic transitions away from mining in different regions across the country. The functionality on all types of devices empowers the most vulnerable in society who often do not have a voice in post-closure discussions. Finally, while it has been developed for South Africa, the concept, design and insights could be applied to any mining country in the world.

CRediT Statement

Megan Cole: Conceptualisation, Supervision, Methodology, Investigation, Writing – Original Manuscript, Writing – Review and Editing, Project Administration, Funding Acquisition; Murad Esau: Methodology,

Software, Investigation, Data Curation, Visualisation, Writing – Original Manuscript, Writing – Review and Editing; Jennifer Broadhurst: Supervision; Tapiwa Chimbganda: Methodology; Amber Abrams: Methodology.

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