A sustainable approach to derelict and ownerless mines in South Africa

by M.J. Cole[1], S. Mudau[2], P. Mohasoa[2]

Affiliation:
[1]University of Cape Town, South Africa
[2]Minerals Council South Africa

Correspondence to:
M.J. Cole

Email:
meganjcole@gmail.com

Dates:
Received: 15 Oct. 2025
Published: April 2025

How to cite:
Cole, M.J., Mudau, S., Mohasoa, P. 2025 A sustainable approach to derelict and ownerless mines in South Africa. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 125, no. 4, pp. 193–208

DOI ID:
https://doi.org/10.17159/2411-9717/796/2025

ORCiD:
M.J. Cole
http://orcid.org/0000-0003-0815-7590

This paper is based on a presentation given at the Mine Closure Conference 2025 19-20 February 2025, Maslow Hotel, Sandton, Johannesburg

Abstract

Derelict and ownerless (D&O) mines in South Africa have been an ongoing concern for over a decade. While some progress has been made to rehabilitate D&O asbestos sites, significant work remains, exacerbated by the growth in illegal mining. There are concerns regarding the accuracy and transparency of the D&O database, lack of oversight, and constrained funding, and the government is increasingly looking to the private sector to fund rehabilitation. Given these challenges, a new, sustainable approach to D&O sites in South Africa is needed to bring clarity and transparency to the process, recognise responsibilities and promote partnerships, and explore economic opportunities at D&O sites to reduce the financial liability and respond to the growing demand for critical minerals. This article has three components: i) reviews of international D&O good practices; ii) it analyses South Africa's current approach and the D&O sites; and iii) proposes a D&O framework that addresses data, risk ratings, responsibilities and rehabilitation, economic opportunities, and stakeholder engagement. The study finds that the majority of the 6,100 so-called abandoned D&O mines are quarries and mine site features, 16% are operational, at least 11% have owners, and only 752 (12%) require rehabilitation. The framework aims to bring clarity and fairness to decision-making and to assign risk and responsibility for rehabilitation and seeks to incorporate economic opportunities to reduce the financial burden of rehabilitation, create jobs for local communities, and respond to the growing demand for critical minerals for the clean energy transition.

Keywords

mining, mine closure, abandoned mines, risk, economic opportunity

Introduction

Abandoned mines – risks and opportunities

Legacy mining issues are common in many mining countries around the world with an estimate of millions of sites globally, although in most countries they are not well documented (Worrall et al., 2009). They are described by various terms, including derelict, ownerless, abandoned, legacy, and orphaned sites and include shafts, pits, and waste rock dumps. They pose risks to public health and safety, the environment (water, land, biodiversity), society and the economy, and have significant policy and financial implications (Bian et al., 2010; Tremblay, Hogan, 2016; Broadhurst et al., 2019). Common characteristics are incomplete remediation of historical mines, responsibility falling to the state and private landholders, and the complexity of potential impacts (Unger et al., 2015). Formal responses to abandoned mines are a relatively recent development, and they range in scope from large-scale landscape level initiatives, such as those implemented in Germany, to small-scale site-level projects focused on individual mines (Cornelissen et al., 2019). Despite significant progress in mine closure regulations and practices around the world, effective rehabilitation of mine-degraded land and waste facilities is hard to achieve (ICMM, 2019). Where rehabilitation is done, it may not eliminate the long-term risks, partly because they are hard to predict (Van Druten, Bekker, 2017; Gule, 2021; Cole, 2024). There is rapidly growing demand for metals and minerals that will contribute to the green energy transition, such as copper, nickel, cobalt, zinc, lithium, rare earth elements, manganese and vanadium (Elshkaki et al., 2016, 2018; IEA, 2023; US Geological Survey, 2024). These so-called critical minerals are essential components in clean energy technologies such as wind turbines, solar panels, battery storage, and electric vehicles. Increasing prices could turn abandoned mines from financial liabilities into economic opportunities.

Mining in South Africa

A brief review of the history of mining in South Africa reveals huge economic, political, institutional

and governance changes over 170 years (Cole, Broadhurst, 2020). Commercial mining began in South Africa in 1852 with Namaqualand copper deposits (Cairncross, 2004), followed by coal (1880), diamonds (1886), gold (1890), tin (1907-1994) (Falcon, 1985; Godsell, 2011), platinum-group metals (PGMs) (1920), manganese and iron ore (1929), and asbestos (1930s-1980s) (Hart, 1988). Mining was the basis for an industrial revolution that transformed South Africa into an economic powerhouse (Wilson, 2011) and stimulated manufacturing, agriculture, and services and led to the development of towns, cities and transport networks (Kane-Berman, 2017). Many mines have closed over the years as they depleted their resources. However, there are currently over 230 operating mines in South Africa producing over 20 different commodities (Cole, 2024). Some old mines are targets for illegal mining, posing a risk to human safety and the natural environment and causing losses in investment, production, and employment for the mining industry. Challenges to rehabilitation in South Africa include a lack of clearly assigned responsibilities, the absence of criteria and standards of rehabilitation, the potential high cost of rehabilitation, the lack of legal clarity, the process and requirements for undertaking government funded rehabilitation, and numerous technical issues (Mhlongo, Amponsah-Dacosta, 2016; Cornelissen, 2017).

Mine closure legislation in South Africa

Prior to 1956, mine closures were not subject to stringent legislative requirements, with mines governed by insufficient environmental regulations under the Mines and Works Act of 1911. Closure planning was introduced in the Minerals Act of 1991, which stipulated that an environmental management programme be submitted, rehabilitation be undertaken, financial provision made, and an application submitted for a closure certificate (Swart, 2003). Since democratic elections in 1994, there have been significant reforms to mining and environmental legislation and the main regulations, which now govern mine closure and rehabilitation in South Africa, are the Mineral and Petroleum Resources Development Act (MPRDA) of 2002 and the National Environmental Management Act (NEMA) of 1998. In 2015, regulations for Financial Provisioning for the Mitigation and Rehabilitation of Environmental Damage Caused by Reconnaissance, Prospecting, Exploration, Mining or Production Operations were promulgated under the Government Notice Regulations GNR1147 in terms of NEMA, designed to achieve an approved sustainable end state.

Other relevant legislation includes the National Water Act (NWA), which governs water use of water for mining related activity, the Mine Health and Safety Act (MHSA), which places safety and occupational obligations on mine rehabilitation and closed mines, the Conservation of Agriculture Act (CARA), which states that degradation of the agricultural potential of soil is illegal, and the Spatial Planning and Land Use Management Act (SPLUMA), which provides a framework for spatial planning and land use management.

A Draft National Mine Closure Strategy (NMCS) was gazetted by the DMRE in 2021, aiming to support existing legislation, address issues around rehabilitation, plan for 'a diverse post-mining economy', and promote closure planning throughout the lifecycle of a mine, and a regional approach to mine closures (DMRE, 2021). The MPRDA requires the mining right holder to fully rehabilitate the mine before the DMRE issues a closure certificate and mandates the DMRE to manage and rehabilitate mines that had been abandoned prior to 2002, known as derelict and ownerless (D&O) mines. D&O mines are non-operational mines, either abandoned by their owners or their owners cannot be traced, with health, safety, and environmental risks that are not being managed. These mines operated under weaker regulatory requirements, and include mines in the Okiep copper belt, the Natal coalfields, asbestos regions, and the Wits goldfields.

South Africa's D&O strategy

In 2009 the Department of Mineral Resources (now the DMRE) developed (but did not gazette) a 'National Strategy on Management of Derelict and Ownerless Mines' with the stated objectives being the compilation and maintenance of an inventory of D&O mines, the identification of priority sites, the development of an action plan to manage the associated risks, and ensuring that all D&O sites are rehabilitated to acceptable levels, i.e., habitable by humans, used for other development activities, or a stable environmental state (DMR, 2009). In the same year, the Auditor-General of South Africa (AGSA) performed an audit of the financial requirements for the rehabilitation of D&O sites (AGSA, 2009). The D&O strategy required the rehabilitation programme to run in parallel at two levels: large- and medium-scale regional programmes – focusing on larger multiple mine clusters that have a cumulative impact on the environment, such as asbestos, gold and coal mines – and small-scale local programmes focusing on mines with a smaller geographical scale but that pose an immediate threat, such as quarries, mine shafts, and trenches that are located close to residential areas (included in the holings programme). The Council for Geoscience (CGS) and Mintek were commissioned as implementing agents for the rehabilitation programme, including managing the D&O database, closing dangerous holings and rehabilitating asbestos mine sites. In 2021 the AGSA published a 'Follow-up Performance Audit at the DMRE on the Rehabilitation of Derelict and Ownerless Mines' which showed that although some progress had been made, there were still many critical areas that needed to be improved (AGSA, 2022). The AGSA noted that managing D&O mines is not just about rehabilitation, but also includes alternatives such as creating a landscape that can support future uses of the land, which could reduce the government's financial liability.

There are several major concerns regarding the current approach to D&O mines in South Africa. Firstly, the national strategy of 2009 was never gazetted and the proposed revision has not been published or gazetted, so there is no written document to review and respond to, and no formal public participation process has been initiated or undertaken by the DMRE. This undermines the validity and legality of the approach. This is despite repeated requests by the mining industry for clarity and transparency in the approach to D&O mine sites. Secondly, the poor track record highlighted by the AGSA (2021) indicates that it will take decades to remediate all D&O sites, partly due to lack of funding but also due to lack of capacity and/or effort. Thirdly, the Government is increasingly calling on the mining industry to participate or contribute to the management and/or rehabilitation of D&O sites, as though this is a shared responsibility rather than the responsibility of the state. An alternative strategic approach and framework for managing D&O sites is clearly required. In this article, a new approach is developed based on data collection and analysis, international practice review, and stakeholder engagement.

Methods

Firstly, a literature review of international practice was undertaken regarding abandoned mines in Australia, the United States

of America (USA), Canada, Chile, Portugal, Brazil, and the Association of Ibero-American Geology and Mining Services (ASGMI), an association of 22 national geological and mining agencies from Spanish and Portuguese speaking countries in South America, Central America, and Western Europe. The review, therefore, covers both developed and developing mining countries to ensure breadth and diversity in contexts. The country approaches were reviewed and common elements were identified together with lessons learned, that can be applied to the South African context.

Secondly, an analysis of the current approach was done, including engagement in the national consultations for the National Mine Closure Strategy and D&O Mines Strategy facilitated by the DMRE and CGS. Efforts were made to obtain the D&O database to undertake an in-depth analysis of South Africa's D&O sites and related risks. The authors were unable to obtain the database so instead analysed the AGSA performance report (2021) and the South African Mineral Deposits database (SAMINDABA), which appears to be the basis for the D&O database. In addition, a GIS shapefile of a subset of the D&O sites was used to perform a spatial assessment of three gold and coal mining regions to identify potential challenges and opportunities around roles and responsibilities.

Thirdly, the international review and national analysis were used to develop a framework for the sustainable management of D&O mine sites. The framework was presented to mining company representatives for review and input.

Results

International practice – management of D&O sites

USA

The USA federal government and its Office of Surface Mining, Reclamation and Enforcement (OSMRE) established an Abandoned Mine Land (AML) Reclamation Programme in 1977 through the Surface Mining Control and Reclamation Act to remediate coal mines that were abandoned before 1977 (EPA, 2024). It established the Abandoned Mine Land Inventory System (e-AMLIS) to store, manage, and report on OSMRE's Inventory of AML problems, including both problems in need of reclamation and those that have been reclaimed. The inventory contains information on the location, type, extent of AML impacts, and reclamation costs and is based upon field surveys by State, Tribal, and OSMRE programme officials. It is updated as new problems are identified and existing problems are reclaimed (OSMRE, 2024). E-AMLIS caters for authorised users and the public, although it appears that it cannot be accessed from South Africa.

The programme is funded by Treasury and by fees charged to operating coal mines based on their production tonnage and type of mine. The fee structure has changed over time and, to date, has collected over USD12 billion (OSMRE, 2024). The OSMRE distributes the funds based on a preset formula (incorporating fee collections, historic coal production, and the AML inventory) to states and tribes who have their own programmes, which prioritise mine pollution problems, and reports to Congress. Priority 1 problems relate to the protection of public health, safety, and property from extreme danger, while Priority 2 problems relate to the protection of public health and safety. All problems involve the restoration of land and water resources and the degraded environment. The OSMRE also transfer funds to the United Mine Workers of America Health and Retirement Funds.

The AMLRP has an awards programme that recognises outstanding reclamation techniques and projects. It also created an Abandoned Mine Land Economic Revitalisation (AMLER) Programme in 2016 to explore and implement strategies that return legacy coal mining sites to productive uses through economic and community development, supporting local investment opportunities that provide for sustainable long-term rehabilitation (OSMRE, 2023). Funding comes from the federal government and is administered by the OSMRE, based on the AML inventory and eligibility of states and tribes. States and tribes work with partners to compile, assess, and select potential projects to submit to OSMRE for vetting. They are encouraged to use the AMLER funding to leverage other public and private funding sources.

Canada

The Canadian government established the multi-stakeholder National Orphaned/Abandoned Mines Initiative (NOAMI) in 2002 at the request of the Canadian Mines Ministers to remediate the ~10,000 abandoned mines located across all jurisdictions in Canada (Government of Canada, 2024). NOAMI focuses on rehabilitation and long-term management of existing sites and best practices to prevent future abandonment through legislation. It addresses five themes: 1) building a national inventory, 2) community perspectives, 3) setting standards and rational expectations, 4) ownership and liability issues, and 5) identification of funding models. Several guidance documents and reports have been published (Tremblay, Hogan, 2016) and a national inventory and interactive map are publicly available. However, it combines several Canadian provincial inventories with different content, definitions, accuracy, and periods (NOAMI, 2004). Abandoned mines are classified as Class A (potential to cause environmental, public health, and public safety concerns – verified or estimated), Class B (limited potential to cause environmental concerns but potential for public health and safety concerns), Class C (public safety concerns but little or no public health or environmental concerns), Class D (no expected environmental, public health or public safety concerns) and Class O (no information available). The NOAMI Advisory Committee comprises government representatives, the Canadian mining industry, environmental non-governmental organisations (NGOs) and Aboriginal peoples and their communities, the Mining Association of Canada, Prospectors and Developers Association of Canada, and mining companies.

NOAMI published a toolkit of funding approaches in 2006 (NOAMI, 2006). Although most jurisdictions in Canada rely on direct government funding from general revenues, other approaches involve government funding through tapping existing revenue streams generated by mining (e.g., mining tax/royalties), government funding through the imposition of a levy on current and future mineral production, federal and provincial cost sharing arrangements from general revenues, and government-industry partnerships.

The province of Ontario has more than half of Canada's abandoned mine sites, as recorded in the Abandoned Mines information system database. Ontario's Abandoned Mines Rehabilitation Programme promotes and funds the rehabilitation of abandoned mine sites to make these lands available for other uses. The Ontario Mining Association and member companies also contribute funds as part of a partnership with the provincial government to complete rehabilitation work on government land. Ontario aggregate producers pay a licencing fee based on production tonnages to fund the Management of Abandoned Aggregate Producers programme.

Australia

In Australia, where there are an estimated 50,000 abandoned mine sites across seven states, a National Strategic Framework for Managing Abandoned Mines in the Minerals Industry was published in 2010 to encourage a strategic approach to the management of abandoned mines that promotes efficiency, sustainability, innovation, and consideration of the unique assets and community values for each mine (MCMPR, MCA, 2010). It was produced by the Ministerial Council on Mineral and Petroleum Resources, which consists of the Australian Government Minister for Resources, Energy and Tourism, and state and territory ministers responsible for minerals and petroleum, and the Minerals Council of Australia. Sites are classed as 'abandoned' once a mining tenure no longer exists, and most date prior to 2000 when the laws were amended to strengthen environmental management. The strategy notes that several abandoned mine sites have become economically viable mines or could become economically beneficial through other land uses. In 2023, Geoscience published the Australia Australian Waste Atlas, which provides spatial and technical information about all mine waste sites in the country to support remining and processing for economic benefit and reducing environmental and social risks. (Geoscience Australia, 2023).

Individual states have their own approaches to abandoned mines (Unger et al., 2012). There are about 120 complex abandoned mine sites in Queensland and the Abandoned Mine Lands Programme has remediated over 450 mine features at 138 sites since 2013 (Queensland Government, 2021). Activities include shaft remediation, monitoring and assessment, disposal of equipment, demolition and decommissioning of infrastructure, management of cultural heritage issues, and stakeholder engagement. In 2021, the state published a Risk and Prioritisation Framework for Abandoned Mine Management and Remediation (State of Queensland, 2021) and a map of all sites is publicly available. A financial provisioning scheme legislation was passed in 2018 to reduce the financial risk to the government when a mineral right holder fails to meet their rehabilitation obligations. Grants provided by the scheme's Financial Provisioning Fund also support the rehabilitation of abandoned mines and improvements in rehabilitation techniques. The scheme is administered by the Scheme Manager, a statutory officer supported by Queensland Treasury.

The State of Western Australia began to develop an inventory of abandoned mine site features in 1999 and set up a Mining Rehabilitation Fund (MRF) in 2012, with an annual industry levy that encourages progressive rehabilitation during mining operations and provides funds to rehabilitate abandoned mine features across the State; interest generated from the fund can be spent on administration and rehabilitation of historically abandoned mine sites (State of Western Australia, 2024). In 2016, an Abandoned Mines Programme was established to provide an overarching framework for prioritising and subsequent rehabilitation and/or management of abandoned mine sites. A Mining Rehabilitation Advisory Panel provides expert and independent advice on project development and expenditure. Abandoned mine sites can be explored in the publicly available Mines and Mineral Deposits database and a spatial dataset can be downloaded (https://minedex.dmirs.wa.gov.au/). Specific rehabilitation projects are described on the Geological Survey of Western Australia website. The state encourages industry and the community to report abandoned mine features via email using an official template.

Portugal

Portugal has many abandoned mines across the country from historic mining of base metals, precious metals, tin, tungsten, radium, and uranium, which pose public health and environmental risks (Carvalho, Diamantino, Pinto, 2016). In 2001, the government developed the Old Mining Areas Remediation Plan and appointed the state-owned company EDM to remediate 175 mines, 61 of which are radioactive. By 2018, 105 out of 199 sites had been remediated at a cost of €80 million with an estimated cost of €60 million for the remaining sites (EDM, 2018). Their strategy involved four phases: 1) inventory, characterisation of sites, and prioritisation of remediation interventions; 2) detailed design and project development; 3) remediation and field work; and 4) monitoring. A national map of all sites is publicly available on the EDM website. Funding for the programme comes from mining royalties from Portuguese mining operators and the European Cohesion Funds. EDM is involved in research and development (R&D) projects investigating new methods of mineral extraction from secondary sources to offset remediation costs.

Chile

Mining has been underway in Chile for centuries, leaving environmental challenges at historic mine sites. In 2002, the National Service of Geology and Mining, SERNAGEOMIN (the technical body responsible for generating, maintaining, and disseminating information on geology and hazards, and for regulating and/or supervising mine safety compliance and mine closure plans) initiated the 'National Registry of Abandoned and/or Inactive Mining Operations', which systematically registered 1,338 abandoned or inactive mines from 2002 to 2019 and incorporated a preliminary risk assessment. Funding was sourced from the Chilean-Japanese cooperation project FOCIGAM (Strengthening Institutional Capacity in Mining Environmental Management). SERNAGEOMIN makes the national database publicly available on its website (https://www.sernageomin.cl/investigacion-de-faenas-abandonadas/).

Chile has 765 tailings dams with 173 (23%) of them being abandoned (SERNAGEOMIN, 2023). The Chilean government promotes the reprocessing of abandoned tailings, which is underway. The Department of Tailings Deposits generates and updates information for the National Registry of Active and Inactive Tailings Deposits, Virtual Atlas and Geochemical Registry of Deposits. SERNAGEOMIN hosts a public cadastre and database for all tailings deposits. The Tailings Programme established in 2017 is a public-private collaborative initiative that develops monitoring tools for physical stability and potential impact on water resources, providing information to authorities, mining companies, and communities. It supports emergency response through a global monitoring system operated by SERNAGEOMIN, the National Observatory of Tailings Deposits. It is funded by the Chilean economic development agency (CORFO) and the Chilean mining sector.

South and Central America

The Association of Ibero-American Geology and Mining Services (ASGMI) is an international association of 22 national geological and mining agencies from Spanish and Portuguese speaking countries in South America, Central America, and Western Europe. In 2020, the ASGMI published a technical glossary on managing mining environmental liabilities and a manual for the inventory of abandoned and inactive mines. A common methodology was developed with a decision tree and four stages: 1) identification, inventory and characterisation of abandoned and inactive mine sites and/or mining environmental liabilities; 2) risk assessment and

Table 1

Summary of approaches to abandoned mines in mining countries

Country	Institutions	Funding	Data and transparency	Sustainability
USA	Federal government, EPA, OSMAR	National treasury and coal mining companies	National publicly available database	Economic repurposing supported
Canada	National and provincial response, industry partnerships	National treasury, Ontario aggregate producers fee	National and provincial public database and map	
Australia	National framework, province-level programmes; Advisory panel gives oversight	Grants from Queensland Financial Provisioning Fund; Western Australia Mining Rehabilitation Fund charges annual industry levy	Province-level publicly available databases and maps; national Mine Waste Atlas	Promotion of economic use of mined land
Portugal	State-owned company EDM	National government and European Union	National inventory and map	R&D projects on waste reprocessing
Chile	SERNAGEOMIN agency, public-private partnership	Chile-Japan cooperation	Publicly available national database	Tailings programme

classification of mining environmental liabilities; 3) reprocessing and/or reuse of mining environmental liabilities; and 4) prioritisation and proposals for remediation of mines. The ASGMI (2019) found that not all geological surveys and mining directorates of its member countries have direct competence in managing mining environmental liabilities.

The state of Minas Gerais, Brazil, developed a 'First Registry of Abandoned and Inactive Mines' that covers sites with no plans to restart operations, without implemented environmental control or monitoring measures, and with characteristics of abandonment and incomplete or absent mine closure processes (Fernandes, De Lima, 2021).

Key insights

While there are differences in approach to managing abandoned mines in different countries, common elements include 1) collecting information on the mine sites to develop an inventory, 2) prioritising sites for rehabilitation based largely on public health and safety and environmental risks, and 3) rehabilitating or managing the sites, generally done by government or a government appointed agency, 4) stakeholder engagement, particularly with community involvement, and 5) identifying appropriate funding models. The countries studied have transparency with regard to their D&O site locations, commodities and risks. Table 1 summarises the key components related to institutional arrangements, funding, data and transparency, and sustainability, in the countries reviewed. An additional element that stands out is the decentralised approach to managing D&O sites, particularly in developed countries. While national governments give strategic direction and funding, states, provinces, or territories have the authority and responsibility to oversee the work.

South Africa's current approach to D&O mines

Data and transparency

The international review shows that it is common practice to maintain a national and/or state/provincial D&O database and that most countries make this publicly available. Although there is an existing South African D&O database owned by the DMRE and maintained by the CGS, the AGSA audit raised several concerns with it, i.e., missing information, duplicates, incomplete fields, outdated status after rehabilitation, and lack of rehabilitation project documentation (AGSA, 2022). The AGSA noted that as the status of mineral deposits changes over time, as new rights are awarded or existing rights expire, the D&O database needs to be regularly updated with input from the DMRE, Mintek, and the CGS. A mining cadastre is essential for this process, however, this is not in place despite calls from the mining industry and foreign investors. As the D&O database is not publicly available (for supposed security reasons), and requests for access to the database have been unsuccessful, it is difficult to assess what information it does and does not contain. The lack of transparency makes it impossible to attract partnerships and investments for potential socio-economic activities. While it would be beneficial to alleviate the burden on the state, this needs to be done using evidence, analysis, and consideration of alternative approaches.

Although the DMRE and AGSA state that there are 6,100 'D&O mines', these include mine site features (such as adits, pits, shafts, dumps, buildings) and quarries and should rather be termed D&O sites. According to the AGSA audit, there are 961 operational sites in the D&O database, 674 sites with mineral right ownership attached, 922 sites on private land, and 276 sites with unknown property ownership. Based on these figures, it seems that there should only be 4,410 unrehabilitated D&O sites in the database. Recent research into operational mines in South Africa shows that there are only 230 operating mines (excluding artisanal and small-scale mines), therefore the majority of the sites must be quarries (Cole, Broadhurst, 2021; Cole, 2024).

Of the 6,100 D&O sites, only 752 have been given a priority rating depending on their potential impact on public health, safety, and the environment, 188 high priority (3%), 184 moderate priority (3%), and 380 low priority (6%), while no rehabilitation necessary is almost half of them (2,908 or 48%). It is unclear why the other 39% (2,385 D&O sites) did not receive a priority rating but it is assumed that they pose very little or no risk. In addition to the priority rating, 2,568 D&O sites are classified as high-risk mining commodities: gold (46%), coal (25%), asbestos (16%), and copper (13%). It appears then that a D&O site can be a high risk commodity but not a priority. The DMRE also identified 1,170 holings (quarries, mine shafts, and trenches) that are located close to residential areas and pose an immediate threat of injury to humans and animals.

By November 2021, only 55 D&O sites (1%) had been rehabilitated (ibid), the majority being asbestos sites, and 507 holings had been sealed and closed (AGSA, 2022). The AGSA estimate that at the current rate, the DMRE would take 100 years to rehabilitate all D&O sites.

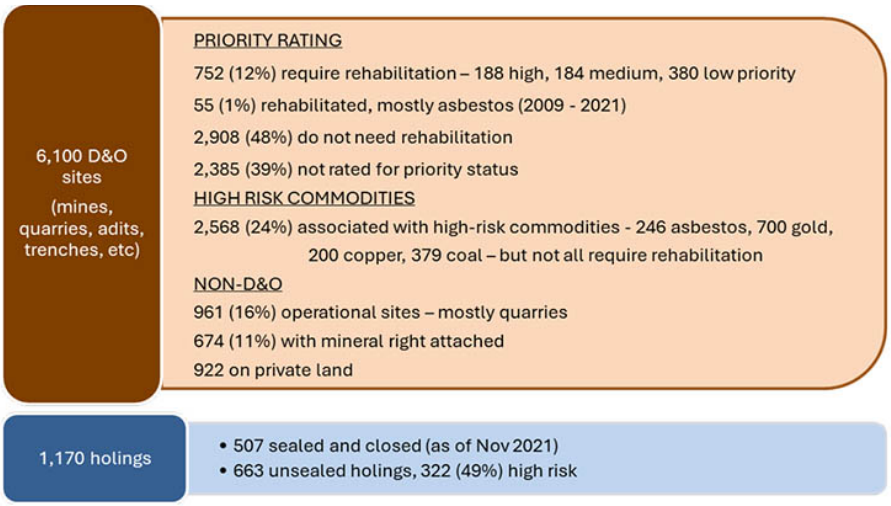

Figure 1—Summary of Auditor-General of South Africa (AGSA) findings on D&O sites, 2021

Another data source that was investigated is the South African Mineral Deposits Database (SAMINDABA) maintained by the Council for Geoscience. A 2012 version of the database was found online, with 8,176 records. The records include mineral deposits (prospect, occurrence, outcrop, seam, reef, vein), quarries, excavations, workings, diggings, pans, trenches, active mines, abandoned mines (shafts and pits), and a few mine dumps and slimes dams. The D&O database maintained by the CGS is therefore a subset of the SAMINDABA database. There are many unnamed sites and many data gaps in the database as well as the scale of the individual sites, and therefore their potential impact and risk vary significantly. The current database is not publicly available and could not be analysed.

Risk and responsibilities

Since 2009, the CGS has been responsible for maintaining the D&O database and Mintek has been responsible for rehabilitating asbestos sites. Mintek developed a secondary asbestos D&O site risk ranking supplementary to the standard protocol and national strategy. Their model uses risk metrics in three categories to measure the potential impact of the site, namely health and safety, environmental, and land utility (including evidence of illegal mine access and the site's potential to hamper future development by sterilising land) (Cornelissen et al., 2019). The value of each risk type is calculated based on the impact and likelihood of occurrence and these are added to calculate the total site risk. The model also includes a consideration of cost and complexity and this is plotted against the total site risk to determine rehabilitation priorities with 'high risk low cost' being the priority followed by 'high risk high cost' (Cornelissen, 2017). Individual mine features are typically grouped into single projects that address all pollution/risk points on a whole-mine scale.

The government established a Rehabilitation Oversight Committee (ROC) consisting of the DMRE, the CGS, and Mintek in December 2009. The ROC was meant to recommend and oversee an annual and three-year cycle implementation plan for rehabilitation projects but, according to the AGSA, has not done so (AGSA, 2022). The AGSA audit also shows that by September 2021, the DMRE had not completed the planned research into high-risk, large-scale, and complex groups of D&O mines with a combined impact on communities and the environment as envisaged in the national strategy.

Issues related to D&O sites have evolved since 2009 and the focus is now on illegal mining, which involves unauthorised people entering unsafe shafts, adits and pits, and unsealing high risk holings that have been sealed in the DMRE holings programme. While the risk of illegal mining appears to be captured in the current Mintek risk rating, it is not reflected in the national D&O strategy or any official DMRE documents.

Funding

Funding for D&O management currently comes solely from the state, which is unsustainable as the national government is under financial pressure and does not have the required budget to effectively rehabilitate all D&O sites. South African communities live in a context of high unemployment, poverty, and growing crime, exacerbated by the COVID-19 pandemic in 2020-2021. The Government is increasingly urging the mining sector to play a role in managing or restoring D&O sites, treating it as a joint responsibility. However, mining companies in South Africa are also under financial pressure and are already carrying the burden of failing state-owned enterprises and local governments. Load shedding, water shortages, and transport failures hinder production and sales (Minerals Council South Africa, 2024). Active mines are facing their own obligations, especially with many nearing the end of their operational lifespan. However, some abandoned mine sites do present an economic opportunity. The combination of valuable commodities, infrastructure, and vacant land has the potential to support remining, waste processing, infrastructure repurposing, or alternative economic activities that create jobs for the local community and remediate the site. There is therefore an opportunity for mining companies to assist the Government with reducing its D&O liabilities for mutual benefit.

Case studies

One of the high-risk commodities in the D&O database is coal. Coal mining has been underway since the 1850s in KwaZulu-Natal and the 1880s in Mpumalanga. Due to the limited legislation, many coal mines were not properly rehabilitated when they closed. Coal mining faces global pressure to reduce CO_2 emissions and implement a just transition that involves supporting workers and communities when mines close (Cole, Mthenjane, Van Zyl, 2023). Many of the operating coal mines are located on farms (the basis of the mineral rights) that had previous mining rights and mines that ceased operations, as shown in Figure 2. The steep rise in electricity

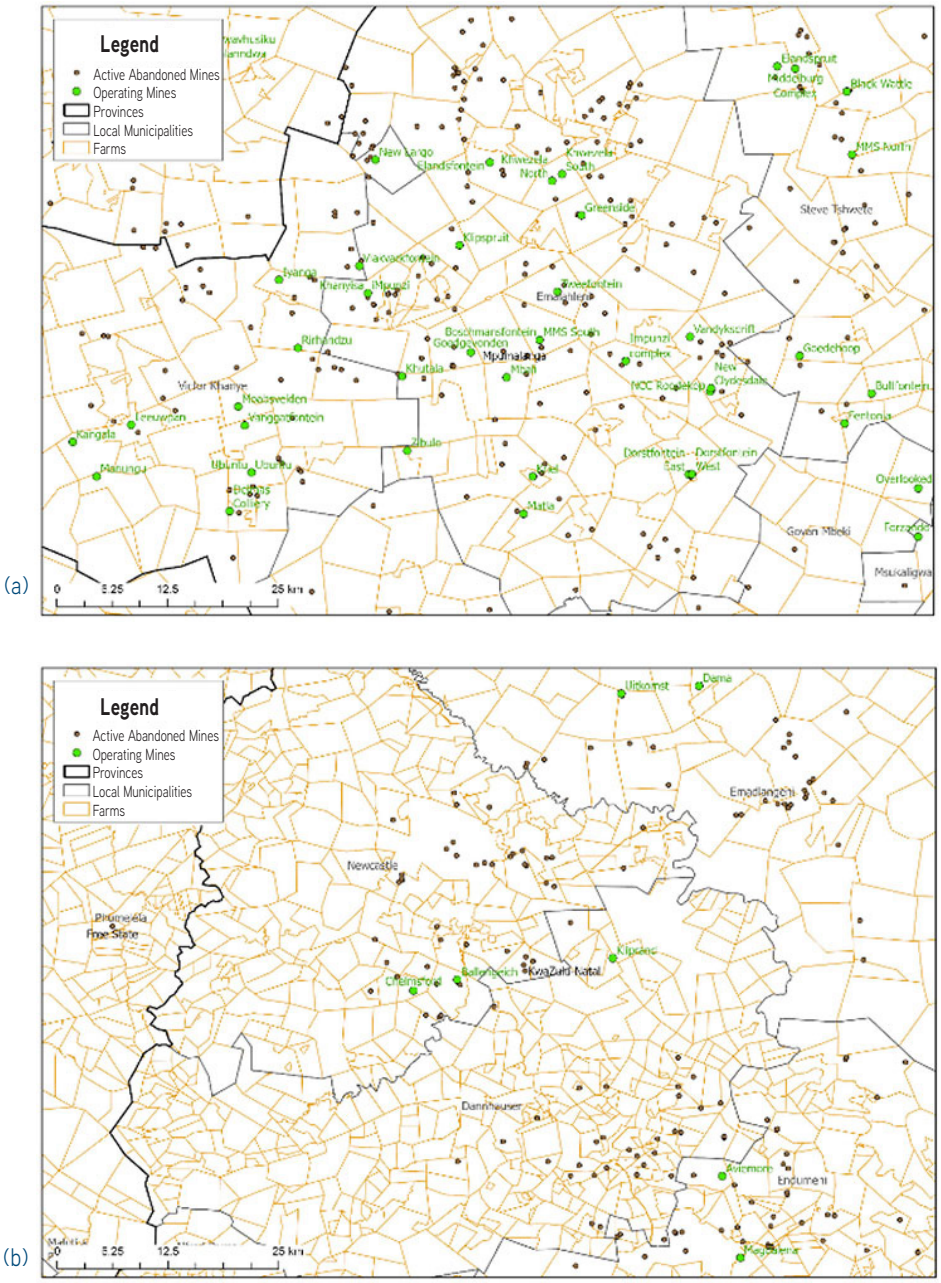

Figure 2—Operating coal mines, D&O sites and farms in A. western Mpumalanga and B. north-western KwaZulu-Natal. Data sources: Operating mines (Cole, 2024); active/abandoned mines (BGIS, 2022), farms (MDB, 2023)

prices in the last decade (Minerals Council South Africa, 2023) has created demand for domestic coal and the D&O sites may provide a local source of coal for illegal miners.

Another high-risk commodity is gold. The five-fold increase in the gold price in the past two decades, with an all-time high in October 2024, has led to the reopening of old mines, tailings retreatment, and waste dump processing, as evident in the Witwatersrand basin, as well as growth in illegal gold mining. The gold price is linked to global financial uncertainty and inflation and is, therefore, likely to remain high for the foreseeable future (JPMorgan, 2023). This represents an economic opportunity for the D&O gold sites in South Africa, which are rated as high risk in the database. Figure 3 shows the location of 14 operating gold mines and numerous D&O sites in the Far West Rand and West Rand, where mining has been underway since the early 1900s. There are 26 tailings dams and six gold processing plants and DRDGold's Far West Gold Recoveries operates a tailings retreatment plant (Cole, Broadhurst, 2022). Most of the mines are part of a mining complex that has been operated by a major mining company for decades. The map shows that there are many D&O sites not located near operating mines or existing mining rights.

A sustainable approach to D&O sites

The ineffectiveness of the current approach, the lessons from international practices, and the new economic opportunities that technology and global demand create, highlight the need for a new approach to D&O mine sites in South Africa. There are five main components that are required, as shown in Figure 4.

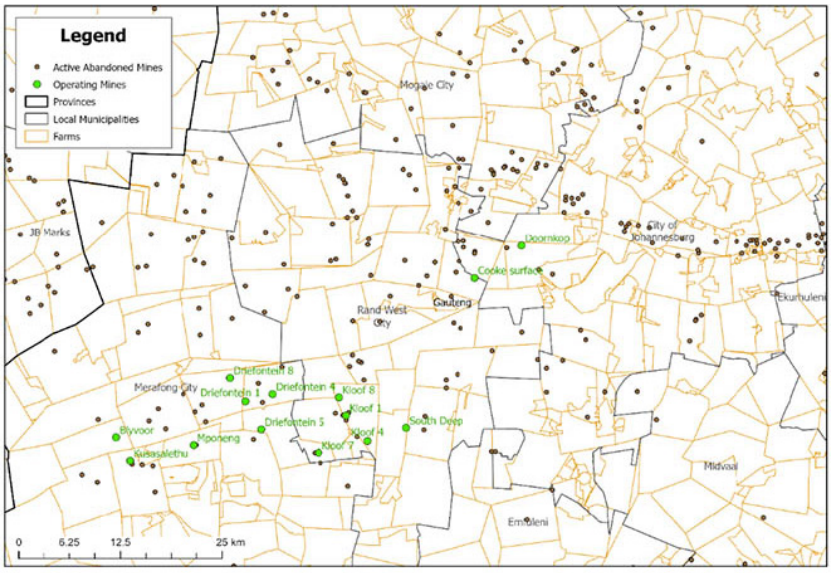

Figure 3—Operating gold mines, D&O sites and farms in the Far West Rand and West Rand. Data sources: Operating mines (Cole, 2024); active/abandoned mines (BGIS, 2022), farms (MDB, 2023)

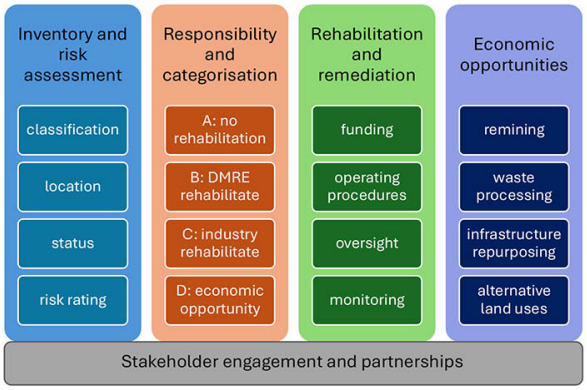

Figure 4—Framework for D&O mine site management

D&O inventory and risk rating system

The first task is to review and update the existing D&O database, ensuring that all the necessary data are captured and accurate figures on D&O sites can be published. Table 2 provides an overview of the information the D&O database should hold so that decisions can be made on when, where, by who, and how to mitigate risk and identify economic opportunities. The data should be stored in a database with a relational database management system (like MS Access), which resides on a web-based server and can be updated and queried at any time by registered and authorised users using a graphical user interface, which limits the user to set dropdown lists and sensible inputs. The development of a spatial tool like the South African Mine Closure Risk and Opportunities Atlas (South African Mine Closure Risk and Opportunity Atlas (arcgis.com) would also be beneficial.

This spatial data will support the determination of responsibility for remediation – an ownerless mine will fall to the state liability, derelict mines on state land also fall to the state. In contrast, derelict sites on existing mining rights will require an assessment of responsibility given asset transfers and remining of previously closed mines. Commodities previously mined and processed must be recorded to identify economic opportunities around reprocessing and remining on D&O sites. Stakeholders need to be identified so that they can be consulted. These include affected communities, civil society organisations, local and district governments, mining companies, environmental NGOs, and national departments. The priority level must be recorded and reviewed as it should take economic opportunities into account.

The risk rating needs to be reviewed to incorporate all relevant social and environmental factors, which will require both desktop analysis and field inspection. Factors that influence the level of risk to the environment and human health and safety from D&O sites are shown in Table 3 and described in Appendix 2. Each one will require quantification (and possibly assigned a weighting) to facilitate a risk rating system that can be used for prioritising remediation and rehabilitation of D&O sites. This needs to build on the existing Mintek risk rating system and the D&O database. The risk categorisation can be applied to three groups: unrehabilitated D&Os, previously rehabilitated D&Os, and land adjacent to D&Os.

Decision tree categorisation of sites

As indicated earlier, D&O sites are currently categorised based on their risk rating (high, medium, low) and their cost to prioritise rehabilitation and determine what actions need to be taken to manage the site. Here, an additional categorisation is proposed to highlight D&O sites that are of interest to the mining industry and to support engagement between the DMRE and the mining industry. A key aim of this proposed new approach to managing D&O sites is to promote new funding models and public-private partnerships. It is based on a decision tree methodology, which asks a series of questions with yes/no answers that produce four scenarios, as illustrated in Figure 5.

The first question is whether rehabilitation is required. The AGSA report indicates that most D&O sites do not need rehabilitation. If rehabilitation is not required, the main action is for the DMRE to monitor the site (scenario A). However, it could also seek partnerships to improve the value of the land or pursue other socio-economic activities. The second question is whether the D&O site is on an existing mining right. If not, the DMRE must rehabilitate the sites and close the holdings (scenario B). If yes, then the third question is whether economic opportunities are possible at the site. If not, the DMRE should explore partnerships with

Table 2

Criteria for characterisation of D&O sites to be included in the database

	Criteria	Details
C1	Type of mine site feature	Vertical shaft, decline shaft, adit, open pit, quarry, trench, tailings dam, waste rock dump, heap, infrastructure.
C2	Associated mine site features	All options above – this will be used for possible integration of rehabilitation.
C3	Geometry	Length, depth, radius.
C4	Location	Latitude/longitude, boundary polygon, local municipality, district municipality, province, farm name.
C5	Neighbouring communities	Names of communities, distance to communities, community population, demographics, and vulnerability.
C6	Proximity to sensitive environmental areas	Distances to SWSA, water bodies, protected areas, conservation areas, endangered ecosystems.
C7	Economic activities	Mines, processing plants, manufacturing, urban centres.
C8	Accessibility	Road access, terrain.
C9	Commodities mined	Primary and secondary metal and mineral products of mining in the past.
C10	Duration of mining	Start and end dates of mining, with reference to key dates in legislation.
C11	Ownership and rights	Ownerless (state liability), derelict on state land (state liability), derelict on mining right.
C12	Stakeholders	DMRE regional office, mining companies, local government, community representatives, civil society.
C13	Risk rating	High, medium, low (after Mintek).
C14	Rehabilitation status	Unrehabilitated, unrehabilitated but planned, rehabilitation underway, rehabilitated, rehabilitated but not safe.
C15	Priority level	Priority 1 – High, Priority 2 – Moderate, Priority 3 – Low.

Table 3

Factors affecting risk of D&O sites and indicative risk ratings*

Factor	High Risk	Medium Risk	Low risk	Data Sources
Size	Large	Medium	Small	Field measurements
Type	Shaft, adit, TSF	Open pit, quarry	Heap, dump	Site visit
Mineral risk to water	High	Medium	Low	Mine Water Atlas
Distance to strategic water source areas	Near	Medium	Far	SWSA shapefiles BGIS
Waste stability	Low	Medium	High	Combined factors
Dust toxicity	High	Medium	Low	Sampling of site
Distance to protected area/ conservation area	Near	Medium	Far	GIS calculations, PACA shapefile (BGIS, 2024)
Agricultural potential – land capability	Arable land	Marginal arable land	Non-arable land	Land capability shapefile
Distance to communities	Near	Medium	Far	GIS calculations
Community vulnerability	High	Medium	Low	Census data, Cole (2024)
Illegal mining potential	High potential	Medium potential	Low potential	Commodity, site visit
Government capacity	Good	Average	Poor	AGSA municipal audits

*more in-depth research is required to quantify the factors.

interested mining companies to rehabilitate the site (scenario C). It should not be mandatory for existing right holders to assume such responsibility. This scenario could also involve grouping the D&O sites to improve efficiencies. If economic opportunities are possible, then the DMRE and interested parties, including mining companies and investors, need to engage in a process to develop options for economic opportunities (scenario D).

Applying this decision tree categorisation to all the D&O sites in the database will produce a list of sites that the mining industry can focus on either for rehabilitation or economic opportunity. This will facilitate discussions with national and local government departments and other organisations that may be interested in partnerships to protect the environment, protect the health and safety of affected communities, and/or develop new economic activities. This will also support assessments of funding models and sources beyond the National Treasury. A good example to learn from is The Impact Catalyst, a collaborative partnership to create mechanisms that drive large-scale, socio-economic development initiatives in mining areas in South Africa through public-private partnerships.

Rehabilitation and remediation

Rehabilitation involves restoring land impacted by mining activities to a sustainable, usable condition and includes minimising loss of land capability and benefiting society (Tanner, Beukes, Möhr-Swart, 2007). Internationally, rehabilitation can be referred to as decommissioning and restoration or remediation and can have different priorities, ranging from community benefits to

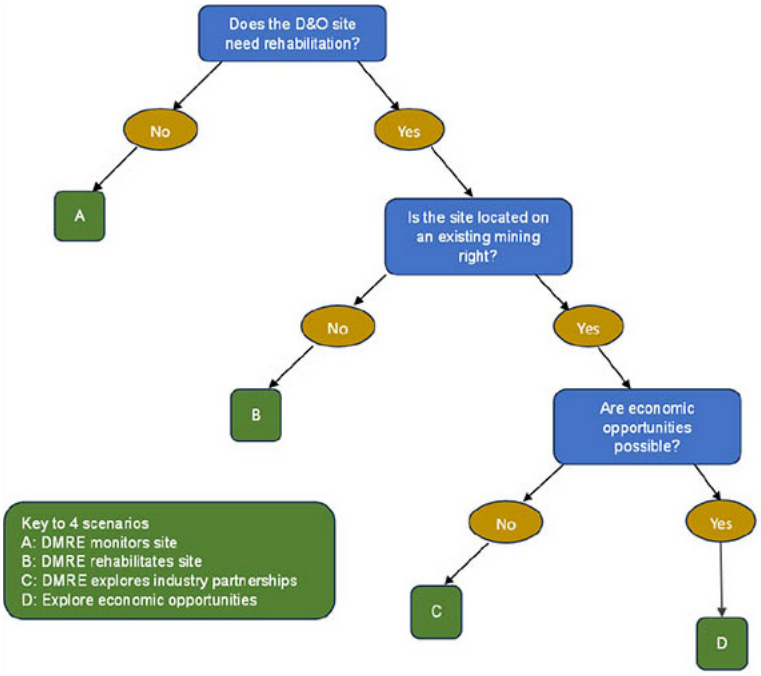

Figure 5—Decision tree for categorising and managing D&O mine sites

Table 4

Factors to be considered for economic opportunities of D&O sites

Factor	Details
Land suitability	Fitness of a given type of land for a defined use in its present condition or after improvements - incorporates land capability, the extent of rehabilitation, and multiple social and economic factors that need to be considered.
Water availability	Consider water requirements, water demand from other users, current and future water supply, water use licenses and water quality required for the intended economic activity.
Biodiversity and tourism	Protected areas and conservation areas (nature reserves, national parks and heritage sites) are potential tourism sites and home to endangered ecosystems.
Energy potential	Renewable energy is a good option for degraded mine land. The energy and transport infrastructure associated with mine sites can support this.
Skills and education levels	Skills and education levels of community members affect the ability to source local employment and procurement for alternative land uses. Low educational attainment is a barrier to local economic development and skills training may be required.
Existing public infrastructure	Proximity, density and capacity of roads, railways, ports, airports, and the electricity grid will affect the access to markets and the feasibility of different economic opportunities.
Economic activities	Current local and regional economic activities indicate what is possible and affect viability of new initiatives. Economic diversification accommodates a wider range.
Land zoning and ownership	State land, private land, and communal/traditional land may need rezoning for alternative land uses - will require support from concerned stakeholders.
District spatial planning	Spatial development frameworks describe goals and plans for economic development and inform budgets and programmes at district and local levels.

original land use, and no net loss of biodiversity. In South Africa, the MPRDA refers to restoring the mine area to its natural or predetermined state but this is qualified by the requirement that rehabilitation must be practicable. Rehabilitation objectives must be aligned with the Environmental Management Plan and Closure Plan objectives and commitments, must provide for sustainable post-mining land use, and should involve a public participation process to define 'end use'.

Rehabilitation should prevent pollution or ecological degradation in the long-term and thus make the environment safe for people to live or undertake other activities. It is, therefore, important to consider both the mine site and the wider area beyond the original mine boundary. This leads to identifying a set of D&O sites that are related or interconnected, and rehabilitating them together. Where there are operating mines working on old mining rights, independent experts may be required to determine whether rehabilitation is required and if so, what the DMRE and the former right holder need to do. Standard operating procedures (SOPs) are required to ensure that the rehabilitation of D&O sites meets international good practices.

There are four environmental elements to consider for rehabilitation and remediation of D&O mine sites – soil, water, waste, and vegetation – while holings can be treated separately. Soil management is a key process in determining rehabilitation

effectiveness and soil stripping guidelines should be followed. Water management is very important for areas affected by acid mine drainage, and for mines with hydraulic interconnectedness and must align with the NWA and relevant guidelines. The disposal of waste must consider long-term impacts or future uses and be strategically placed and managed based on the potential hazard of the material, as per regulations. Vegetation used in rehabilitation will be determined by the planned land use for the site and biodiversity objectives. Revegetation can simply be used to protect against soil erosion or can land the foundation for agriculture and will then take soil, climate and terrain into account.

Progress on rehabilitation should be monitored and reported on an annual basis and included in the D&O database. Reporting should include the commodity, the type of site, the risk level, the implementing agent responsible for rehabilitation, the cost per site, and the source of the funding. The DMRE's Rehabilitation Oversight Committee should include industry representation to ensure there is transparent discussion on planning and to enable collaborative partnerships for rehabilitation.

Funding models

The current funding model for the rehabilitation of D&O sites in South Africa is that the national government covers all costs from general revenues. This is unsustainable and alternative approaches must be considered carefully. Government funding could use existing revenue streams generated by mining (e.g., mining tax/royalties). The government could set up cost-sharing arrangements with provinces, though South African provinces face significant financial constraints. Government-industry partnerships need to be investigated, particularly for D&O sites near operating mines, but could also be developed by commodity for areas without operating mines. The advantages of government-industry partnerships are that more money can be generated, it promotes a sense of partnership and collaboration, and by providing some liability relief companies are more likely to get involved. The disadvantages are that a minor contributor may end up paying for all the rehabilitation costs if other parties lack funds to pay their share. Another option is private sector adoption programmes where companies 'adopt' specific D&O sites and rehabilitate them. Finally, international donors such as multilateral development banks could support rehabilitation and economic opportunity programmes that can benefit local communities significantly. For example, rehabilitating and repurposing coal sites to benefit the coal mining communities in Mpumalanga would fit into the current focus on the just transition being funded by donors.

It would also be helpful to explore capitalising on existing environmental management policies and incentives for business participation in D&O site management. There are four policy instruments that may provide funding: 1) forest carbon offsets/credits, 2) tax breaks for private entities engaging in rehabilitation, particularly in cases where the rehabilitation would yield economic gains, 3) consolidation of biodiversity offsetting projects to yield tangible results, and 4) DMRE conducting a large-scale strategic environmental assessment with strong public participation engagement to attract and fast–track investment and implementation of projects.

Identifying economic opportunities

It is clear from lessons learned from international practices, and the growth in illegal mining, that there are economic opportunities related to D&O mine sites. Illegal mining needs to be addressed to ensure it is stopped or becomes legal and beneficial to communities, industry, and the government. Of particular interest for D&O sites in South Africa is copper, which was once mined in the Northern Cape, and is rated as high risk in the D&O database. Recent exploration has indicated significant potential for opening up old mines, most notably at Rietberg copper mine near Concordia, which was abandoned in the 1980s (SAHRA, 2020), and the Prieska copper-zinc mine, which closed in the 1990s (Orion Minerals, 2023).

There are four potential avenues to explore for economic opportunities, as shown in the framework in Figure 4. Remining minerals and metals involves reviewing old mine sites and assessing their economic potential for mining at different scales. Waste processing involves mineral processing of old rock waste dumps and tailings dams that contain economically valuable minerals and metals. Infrastructure repurposing involves finding new uses for abandoned buildings, water reservoirs, electricity networks, rail and roads. Alternative land use applies where the mine site cannot be remined, processed or repurposed. There are a wide range of possible land uses (Cole et al., 2024) and their economic viability will be informed by a range of environmental, social, and economic factors described in the following, including land suitability, water availability, renewable energy potential, local economic activities, and district spatial planning. These factors need to be considered within local and regional contexts, current and long-term requirements, and quantified where possible. It is important to assess and consider the social and economic aspects related to land use opportunities at the site location. Social factors include community skills and education levels, economic factors include public infrastructure, local and regional economic complexity, land ownership, and financial provisions.

Risk-opportunity matrix

Once a risk assessment has been completed for each site and an assessment of economic opportunities has been done, the two can be combined, and all D&O sites can be plotted on a 2-by-2 matrix, as shown in Figure 6. The four quadrants of the matrix show a combination of risk and opportunity. High-risk, high-opportunity sites will require immediate attention, with economic opportunities assessed before rehabilitation is done, as it may not be necessary. High-risk low-opportunity sites will require immediate rehabilitation to minimise risk to the environment and people. Low-risk high-opportunity sites should be collated, and feasibility studies performed to assess the economic opportunity in more detail. Low-risk low-opportunity sites can be monitored until the high-risk and high-opportunity sites have been addressed. This is similar to the current priority matrix used by Mintek, which looks at risk and cost but instead highlights the economic opportunities that could turn the costs into profitable investments.

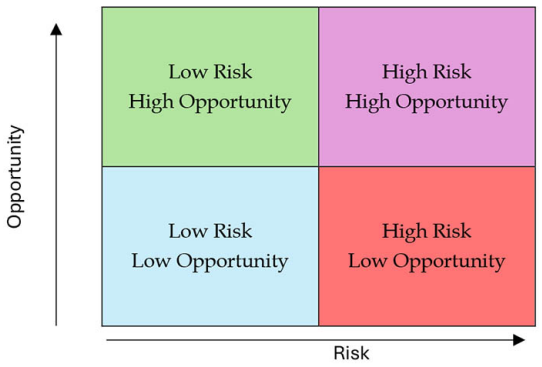

Figure 6—Risk versus opportunity matrix for D&O sites

Stakeholders and partnerships

In South Africa, public participation meetings and consultations are held to inform stakeholders on developments to obtain their perspectives and involve them in the decision-making process. Various provisions of the MPRDA require the holder of a mining right to notify or consult with the affected landowners or communities. Stakeholder mapping is required to ensure all affected parties are included in rehabilitation and to identify economic opportunities. It also helps analyse power dynamics and the relationships between stakeholders to anticipate how that may affect the decision-making process. An open and transparent approach that involves stakeholders in the management and planning of a rehabilitation project can give stakeholders a sense of ownership of the rehabilitation and help improve awareness about issues requiring management (MCMPR, MCA, 2010). Stakeholder participatory processes are increasingly being incorporated into post-closure land use decision-making and selection approaches (Rosa et al., 2018; Everingham et al., 2018, 2020; Measham et al., 2022). Setting 'joint' rehabilitation goals and including key matters such as defining the future beneficial uses for a site, builds trust and improves stakeholder support for abandoned mine site projects. Determining economic opportunities is a difficult task as different stakeholders have different needs and values. Understanding these differences is important and will improve the chances of success. A participatory process is essential to support more inclusive decision-making in South Africa. It can achieve the following aims: identify the objectives and priorities of each stakeholder group, reach a consensus on shared shareholder objectives and values, and determine the most viable options for rehabilitation and economic opportunities. Stakeholders are shown in Table 6.

Discussion

Lessons learned from international practice

South Africa currently has a draft National Mine Closure Strategy (NMCS) to address rehabilitation issues, plan for a diverse post-mining economy, and promote closure planning. It also has a National Strategy on Management of D&O Mines (2009) that was never gazetted for public comment. The AGSA has highlighted many issues with the current management of D&O sites, and the international review in this article has shown several ways South Africa is lagging. Most counties reviewed make their data available to the public in a map or downloadable database, and some even have a system for including public comment and identification of D&O sites. The developed countries generally take a decentralised approach to managing D&O sites, giving authority and responsibility to sub-national levels of government. Other countries have a range of funding models that take the burden off the national treasury and build partnerships with the private sector. A fairly recent development is the attention paid to the economic value of the D&O sites, which can bring jobs back to old mining regions and reduce the financial liability of these sites.

Testing the framework

This article has described the development of a new sustainable approach to D&O sites in South Africa. The D&O management framework proposed is based on international best practices and what was publicly available at the time (early 2024). It is important that the D&O database is examined in more detail and that two or three case studies are used to test the framework. Ideally, the case studies would be located in copper, gold, and coal areas where the risks are highest, there is potential for economic opportunities and funding, and there are operating mines or mining right holders and, therefore, potential for collaboration between government and industry. Conducting a detailed assessment at a site level is crucial to determine the status of Mining Rights regarding the rehabilitation of existing liabilities and the availability of financial provisions. The D&O database is not publicly available due to concerns over illegal mining. However, the DMRE has stated that it would provide sections of data for specific objectives. Therefore, an application can be made for the parts of the database related to the defined case studies. Combining the spatial and tabular D&O site data with data on operating mines and mineral rights, as indicated in the examples in this article, as well as data on closed/inactive mines and mining companies that operated in the past will enable a more in-depth analysis of the challenges, risks, and economic opportunities.

Application of the framework

The South African Government is increasingly calling on the mining industry to participate or contribute to the management and/or rehabilitation of D&O sites as though this is a shared responsibility. The financial provisions of the MPRDA should cover the mine sites since 2002, while sites abandoned prior to

Table 6

Stakeholders involved in D&O site management and development

Stakeholders	Role
DMRE national	Implementation of regulations.
DMRE regional offices	Oversight of D&O management in region.
CGS	Management of the D&O database.
Mintek	Rehabilitation of D&O sites.
National DWS	Water management regulations authority.
National DFFE	Financial provisions regulations authority.
Minerals Council	Advocacy and convening mining industry.
Mining companies	Financial support and/or management of specific D&O sites.
Commodity associations	Public-private partnerships.
SAPS	Management of illegal mining.
Investors	Funding for economic opportunities.
Communities	Input into rehabilitation goals and economic opportunities.
Civil society	Input into rehabilitation goals and economic opportunities.
Academia	Input into suitable economic opportunities.

2002 are the responsibility of the state. There are many old mining areas, which have been abandoned for decades and do not have any operational mines or mining rights in their area. The lack of transparency regarding the D&O database makes it impossible to attract partnerships and investments for potential socio-economic activities. While it would be beneficial to alleviate the burden on the state, this needs to be done using evidence, analysis, and consideration of alternative approaches. The framework proposed in this article addresses both the needs of the private sector and the government. It aims to bring clarity and fairness to the decision-making process and responsibilities regarding D&O sites through a comprehensive and transparent database risk rating and an easy-to-follow decision tree. It also seeks to expand the narrow view of risk to consider economic opportunities, which can significantly reduce the financial burden of rehabilitation, create jobs for local communities, and respond to the growing demand for critical minerals for clean energy transition.

Funding Information

This work was funded by the Minerals Council South Africa.

Acknowledgements

We are grateful to the staff at the Minerals Council who supported the work in particular Nikisi Lesufi and Ursula Brown.

Author Contributions

MC: conceptualisation, data collection, analysis, visualisations, writing the paper.
SM and PM: conceptualisation, review of drafts, funding.

Conflict of Interest

None to declare.

References

AGSA. 2009. *Report of the Auditor-General to Parliament on a performance audit of the rehabiliation of abandoned mines at the Department of Minerals and Energy*. Pretoria: Auditor-General South Africa.

AGSA. 2022. *Follow-up Performance Audit at the department of Mineral Resources and Energy on the rehabilitation of derelict and ownerless mines*. Pretoria. Available at: http://sawic.environment.gov.za/documents/10656.pdf

AGSA. 2023. *Consolidated General Report on local government audit outcomes MFMA 2020-21, AG Consolidated General Report on the Local Government Audit Outcomes FY 2021/22*. Pretoria: Auditor-General of South Africa.

BGIS. 2022. Active and Abandoned Mines 2012. SANBI Biodiversity-GIS.

Bian, Z. 2010. Environmental issues from coal mining and their solutions. *Mining Science and Technology*, vol. 20, no. 2, pp. 215–223. doi: 10.1016/S1674-5264(09)60187-3

Broadhurst, J. 2019. *Resource Efficient and Socially Responsible Approaches for the Integrated Management of Mine Waste: Understanding the Risks , Opportunities , Enablers and Barriers*. Water Research Commission. Available at: https://wrc.org.za/?mdocs-file=59098

Cairncross, B. 2004. The Okiep copper district Namaqualand, Northern Cape Province South Africa. *The Mineralogical Record*, vol. 35 (July-August), pp. 289–317.

Carvalho, E., Diamantino, C., Pinto, R. 2016. Environmental Remediation of Abandoned Mines in Portugal – Balance of 15 Years of Activity and New Perspectives, *Mining Meets Water - Conflicts and Solutions*, (1995), pp. 554–561.

Cole, M. J. 2024. A Mine Closure Risk Rating System for South Africa. *Mining*, vol. 4, pp. 58–78. doi: 10.3390/mining4010005

Cole, M. J. 2024. *Developing Mine Closure Risk Ratings and a Post-closure Opportunity Framework for South Africa*. Final Report to the Water Research Commission of South Africa. Water Research Commission.

Cole, M. J., Broadhurst, J. L. 2020. Mapping and classification of mining host communities: a case study of South Africa. *The Extractive Industries and Society*, vol. 7, no. 3, pp. 954–964. doi: 10.1016/j.exis.2020.06.007

Cole, M. J., Broadhurst, J. L. 2021. Measuring the sustainable development goals (SDGs) in mining host communities: A South African case study. *The Extractive Industries and Society*, vol. 8, no. 1, pp. 233–243. doi: 10.1016/j.exis.2020.11.012

Cole, M. J., Broadhurst, J. L. 2022. Sustainable Development in Mining Communities: The Case of South Africa's West Wits Goldfield. *Frontiers in Sustainable Cities*, vol. 4, (June), pp. 1–15. doi: 10.3389/frsc.2022.895760

Cole, M. J., Mthenjane, M., Van Zyl, A.T. 2023. Assessing coal mine closures and mining community profiles for the 'just transition' in South Africa. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 123, no. 6, pp. 329–342. doi: 10.17159/2411-9717/2689/2023

Collett, A. 2013. The impact of effective (geo-spatial) planning on the agricultural sector. *South African Surveying and Geomatics Indaba.* 22-24 July 2013. Kempton Park, South Africa.

Cornelissen, H. 2017. The development of a qualitative ranking tool for the preliminary selection of abandoned asbestos mine sites for rehabilitation. *Proceedings of the World Congress on New Technologies*, pp. 1–5. doi: 10.11159/icepr17.145

Cornelissen, H. 2019. Challenges and strategies of abandoned mine rehabilitation in South Africa: The case of asbestos mine rehabilitation. *Journal of Geochemical Exploration*, 205 (August), p. 106354. doi: 10.1016/j.gexplo.2019.106354

DMR. 2009. *The National Strategy for the Management of Derelict and Ownerless Mines in South Africa*. Pretoria: Department of Mineral Resources.

DMRE. 2021. *Publication of the Draft Mine Closure Strategy 2021 for Public Comments*. Pretoria, South Africa: Department of Mineral Resources and Energy.

Elshkaki, A. 2016. Copper demand, supply, and associated energy use to 2050. *Global Environmental Change*, vol. 39, pp. 305–315. doi: 10.1016/j.gloenvcha.2016.06.006

Elshkaki, A. 2018. Resource Demand Scenarios for the Major Metals. *Environmental Science and Technology*, vol. 52, no. 5, pp. 2491–2497. doi: 10.1021/acs.est.7b05154

EPA. 2024. *EPA Superfund, United States Environmental Protection Agency.* Available at: https://www.epa.gov/superfund (Accessed: 20 February 2024).

Falcon, L.M. 1985. Tin in South Africa. *Journal of The South African Institute of Mining and Metallurgy*, vol. 85, no. 10, pp. 333–345.

FAO. 1981. A framework for land evaluation. Food and Agriculture Organisation.

Fernandes, P.R.M., De Lima, H.M. 2021. A framework for ranking the environmental risk of abandoned mines in the state of minas gerais/Brazil. *Sustainability (Switzerland)*, vol. 13, no. 24. doi: 10.3390/su132413874

Geoscience Australia. 2023. *Atlas for Australian Mine Waste*. Available at: https://portal.ga.gov.au/persona/minewaste (Accessed: 26 July 2023).

Godsell, S. 2011. Rooiberg: The little town that lived. *South African Historical Journal*, vol. 63, no. 1, pp. 61–77. doi: 10.1080/02582473.2011.549374

Government of Canada. 2024. *NOAMI.* Available at: https://abandoned-mines.org/en/ (Accessed: 20 February 2024).

Gule, N. 2021. *Factors contributing to unsuccessful rehabilitation: a case study investigating the rehabilitation practices in Opencast Coal Mines in the Mpumalanga Province, South ….* University of Cape Town. Available at: https://open.uct.ac.za/handle/11427/33709%0Ahttps://open.uct.ac.za/bitstream/handle/11427/33709/thesis_ebe_2021_gule nontobeko.pdf?sequence=1&isAllowed=y

Hart, H.P. 1988. Asbestos in South Africa. *Journal of The South African Institute of Mining and Metallurgy*, vol. 88, no. 6, pp. 185–198.

Hattingh, R. 2018. *Framework to guide mine-related land use planning towards optimisation of the coal mining rehabilitated landscape*. University of Pretoria. Available at: https://repository.up.ac.za/handle/2263/65312%0Ahttps://repository.up.ac.za/bitstream/handle/2263/65312/Hattingh_Land_2018.pdf?sequence=1

ICMM. 2019. *Integrated Mine Closure Good Practice Guide*, 2nd edition. London: International Council for Mining and Metals (ICMM). doi: 10.2298/theo1704091s.

IEA. 2023. *Critical Minerals Market Review 2023*. Critical Minerals Market Review 2023. International Energy Agency. Available at: https://www.iea.org/reports/critical-minerals-market-review-2023/introduction

Kane-Berman, J. 2017. Mining in SA: Then, now and into the future. *Politicsweb*. Available at: https://www.politicsweb.co.za/archive/mining-in-sa-then-now-and-into-the-future--irr

Lèbre, É. 2020. The social and environmental complexities of extracting energy transition metals. *Nature Communications*, vol. 11, no. 1, pp. 1–8. doi: 10.1038/s41467-020-18661-9

Le Maitre, D. 2018. *Identification, Delineation and Importance of the Strategic Water Source Areas of South Africa, Lesotho and Swaziland for Surface Water and Groundwater*. Pretoria: Water Research Commission.

MCMPR and MCA. 2010. *Strategic Framework for Managing Abandoned Mines in the Minerals Industry*. Ministerial Council on Mineral and Petroleum Resources, Minerals Council of Australia.

MDB. 2023. *Municipal Demarcation Board boundary data main files*. Available at: http://www.demarcation.org.za/index.php/downloads/boundary-data/boundary-data-main-files

Mhlongo, S.E., Amponsah-Dacosta, F. 2016. A review of problems and solutions of abandoned mines in South Africa. *International Journal of Mining, Reclamation and Environment*, vol. 30, no. 4, pp. 279–294. doi: 10.1080/17480930.2015.1044046.

Minerals Council South Africa. 2023. *Facts & Figures Pocketbook* 2022. Johannesburg: Minerals Council South Africa.

Minerals Council South Africa. 2024. *Facts and figures Pocketbook* 2023. Minerals Council South Africa. doi: 10.1007/978-3-662-62217-9_13

NOAMI. 2004. *NOAMI Interactive Maps, National Inventory.* Available at: http://noami.org/InteractiveMaps (Accessed: 4 March 2024).

NOAMI. 2006. *Orphaned and Abandoned Mines: A Workshop to Explore Best Practice Winnipeg*, Manitoba Oct 26-27 2006. Winnipeg, Manitoba, Canada: NOAMI.

Orion Minerals. 2023. *Prieska Copper Zinc Mine*. Available at: https://www.orionminerals.com.au/projects/prieska-copper-zinc-project/ (Accessed: 28 February 2023).

OSMRE. 2023. *Abandoned Mine Land Economic Revitalization (AMLER) Program, Office of Surface Mining Reclamation and Enforcement*. Available at: https://www.osmre.gov/programs/reclaiming-abandoned-mine-lands/amler

OSMRE. 2024. *Reclaiming Abandoned Mine Lands.* Available at: https://www.osmre.gov/programs/reclaiming-abandoned-mine-lands (Accessed: 10 April 2024).

Owen, J.R. 2020. Catastrophic tailings dam failures and disaster risk disclosure. *International Journal of Disaster Risk Reduction*, 42. doi: 10.1016/j.ijdrr.2019.101361

SAHRA. 2020. HIA Copper Mines Namaqualand. South African Heritage Resources Agency.

Schoeman, J. L. 2002. *Development and application of a land capability classification system for South Africa*. Pretoria.

Simate, G. S., Ndlovu, S. 2014. Acid mine drainage: Challenges and opportunities. *Journal of Environmental Chemical Engineering*, vol. 2, no. 3, pp. 1785–1803. doi: 10.1016/j.jece.2014.07.021

Skowno, A.L. 2019. *National Biodiversity Assessment 2018: The status of South Africa's ecosystems and biodiversity - Synthesis Report.* Available at: http://opus.sanbi.org/handle /20.500.12143/6362

State of Queensland. 2021. *Risk and prioritisation framework for abandoned mine management and remediation*. Available at: https://www.qld.gov.au/environment/land/management/abandoned-mines/management

State of Western Australia. 2024. *Abandoned Mines Program, Abadoned Mines Program*. Available at: https://www.dmp.wa.gov.au/Geological-Survey/Abandoned-Mines-Program-29296.aspx (Accessed: 20 February 2024).

Swart, E. 2003. The South African legislative framework for mine closure. *Journal of The South African Institute of Mining and Metallurgy*, vol. 103, no. 8, pp. 489–492.

Tanner, P., Beukes, J. and Möhr-Swart, M. 2007. G*uidelines for rehabilitation of mined land*. Chamber of Mines of South Africa. Available at: http://www.chamberofmines.org.za/work/environment/environmental-resources/send/26-environmental-resources/349-rehabilitation-guidelines-29november

Tremblay, G.A., Hogan, C.M. 2016. Managing Orphaned and Abandoned Mines – A Canadian Perspective. *Dealing with Derelict Mines Summit*, pp. 1–25. Available at: https://www.crccare.com/knowledge-sharing/derelict-minessummit/%0Apresentations

Unger, C. 2012. Mapping impacts and prioritising rehabilitation of Abandoned Mines at a national level in Australia. *Life of Mine Conference,* (December 2014).

Unger, C. J. 2015. A jurisdictional maturity model for risk management, accountability and continual improvement of abandoned mine remediation programs. *Resources Policy*, vol. 43, pp. 1–10. doi: 10.1016/j.resourpol.2014.10.008

US Geological Survey. 2024. *Mineral commodity summaries 2024*. United States Geological Survey. Available at: https://doi.org/10.3133/mcs2024

Wilson, F. 2011. Historical roots of inequality in South Africa. *Economic History of Developing Regions*, vol. 26, no. 1, pp. 1–15. doi: 10.1080/20780389.2011

Worrall, R. 2009. Towards a sustainability criteria and indicators framework for legacy mine land. *Journal of Cleaner Production*, vol. 17, no. 16, pp. 1426–1434. doi: 10.1016/j.jclepro.2009.04.013

WRC. 2018. *The South African Mine Water Atlas*. Pretoria: Water Research Commission

Van Druten, E.S., Bekker, M.C. 2017. Towards an inclusive model to address unsuccessful mine closures in South Africa. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 117, no. 5, pp. 485–490. doi: 10.17159/2411-9717/2017/v117n5a10. ◆

Appendix 1

Factors influencing risk from D&O sites

Mineralogy and water

The mineralogy and geochemistry of the site influence the risk posed to groundwater and surface water resources and human health. The South African Mine Water Atlas presents mineral risk ratings in key thematic maps regarding 'mineral provinces', 'mineral risk', 'mining activity risk', 'groundwater vulnerability', 'surface water threat', and 'mine water threat' (WRC, 2018). Mineral provinces are regarded as mineralised zones that are similar in terms of their host rock geology and mineralogy. Mineral risk maps indicate the assessed risk of acid production and/or leaching of constituents. Mining activity risk maps indicate the assessed relative risks against the dominant mining methods associated with mineral extraction. Groundwater vulnerability and surface water threat maps reflect the vulnerability of those water sources to mining activities. The groundwater vulnerability rating is based on the type of mining activity as the mining depth is considered to have varying impacts on aquifer systems. The threat to surface water resources is reported for the quaternary catchments within the assessed mineral provinces. Each of the component risk profiles can be mapped and understood individually or combined as 'mine water threat' mapping.

A major concern in gold and coal mining areas is the formation and dispersion of acid mine drainage (AMD) due to weathering of the sulphide mineral pyrite. The formation of AMD can continue to be dispersed into the surrounding environment for hundreds of years, with the acidity, salts, and metals impacting the quality of water sources and soils, the growth of local vegetation, and the health of living organisms and ecosystems (Simate, Ndlovu, 2014). Another primary concern of gold mining is the radioactive element uranium. Uranium can bio-accumulate in food chains and endanger ecosystems and people who may experience genetic and non-genetic changes.

An additional consideration are sites that negatively impact South Africa's surface and groundwater strategic water source areas (SWSA), which produce a disproportionate amount of the country's water (Le Maitre et al., 2018). Many D&O sites are located within or close to an SWSA, which needs to be factored into the risk rating.

Dust

If mine sites are not rehabilitated, they can release potentially toxic elements into the air through dust, which is transported by wind and can travel long distances. Exposure to dust is associated with respiratory infections, heart diseases and lung diseases, and people with existing respiratory diseases are at higher risk. Dust from mine waste can contaminate soil and hinder agriculture. Discarded coal dumps may contain low-quality fine coal, making them susceptible to spontaneous combustion, which creates air pollution and affects human health.

Waste stability

Mining generates waste rock dumps and mine tailings, a slurry of rock, water and chemicals, which are stored yearly in dams or tailings storage facilities (TSFs) and are a source of disaster risk and pollution (Owen et al., 2020). Climatic, topographic and tectonic factors play a role in the stability of TSFs, including exposure to earthquakes, tropical cyclones, high winds, heavy rainfall, and steep terrain; these five factors can be quantified and combined to form a TSF failure risk rating (Lèbre et al., 2020).

Biodiversity

Pollution from D&O sites can have a negative impact on local biodiversity in terrestrial and aquatic environments. All critically endangered, endangered, vulnerable, and least threatened ecosystems have been identified and mapped in the 2018 National Biodiversity Assessment, the primary tool for monitoring and reporting on the state of biodiversity in South Africa (Skowno et al., 2019) and spatial files are available on the BGIS website. Sites located at or near critically endangered ecosystems are a higher risk than those of the other ecosystem threat categories. Sites in or near nature reserves and parks also need to be considered higher risk. The DFFE maintains a spatial database on protected areas and conservation areas (PACA) – protected areas are set aside primarily for nature and biodiversity, and conservation areas permit other land uses, as defined in the National Environmental Management: Protected Areas Act of 2003.

Agriculture and land capability

Agriculture can be significantly hindered by mining, through water and air pollution and land degradation. Land capability refers to its agricultural potential, while land suitability depends on economic and social factors in addition to environmental factors. Hence, an area of land can be capable of crop production but deemed suitable

for urban development or mining. South Africa's national land capability classification uses soil, climate, and terrain to differentiate between arable land suitable for cultivation (classifications I, II, and III), marginal land suitable for light cultivation (classification IV), grazing land (classification V, VI, and VII) and wilderness (classification VIII) (Schoeman et al., 2002). South Africa is largely a semi-arid country with limited land capable of supporting sustainable crop production (Collett, 2013), and high potential arable land overlaps with mineral resource rich regions, particularly in Mpumalanga and Gauteng. Failure to manage topsoil during rehabilitation reduces the capability of the land beyond mining (Hattingh, 2018).

Affected communities and socio-economic vulnerability

Communities located close to D&O sites are at risk in terms of health and safety. It is important to know how many people are exposed and how close they live to the site, as there can be significant differences in impact over a few kilometres. Their living conditions (access to basic services, household goods, access to the internet), education and health can be determined from household surveys like the census and the Community Survey undertaken by Statistics South Africa. These can be combined to create a vulnerability index that is comparable across communities. Of particular interest is the main water source used (water scheme, river, water tanker, borehole, etc.) and informal housing, as people using untreated water and living in informal settlements are at higher risk.

Potential for illegal mining

Disused and unrehabilitated mines and dumps can become a target for illegal mining activities. Whilst in many cases these activities are driven by poverty and unemployment, in South Africa, illegal miners known as 'Zama Zamas' are often heavily armed and associated with significant criminal gang activity and illicit trade. Despite calls for assistance from communities and industry, illegal mining continues unchecked in the country. Apart from the direct safety and security risks posed by such activities, illegal mining can also adversely affect the physical stability of mine shafts and workings. Gold, coal, diamond, and chrome mines are known for illegal mining in South Africa.

Government capacity

While the national DMRE is responsible for the management of D&O sites, the provinces are responsible for health care, education and social development, whilst district municipalities are responsible for capacity building in local municipalities, initiating economic development and planning of land-use. In contrast, local municipalities are responsible for the provision of basic services such as water, wastewater, and electricity. As each of these plays a part in managing D&O sites, it is necessary for sub-national governments to be able to mitigate risks related to these sites. Each year, the AGSA assesses the financial state and performance management of all the country's municipalities and provides an overall rating for each municipality, ranging from a clean audit result to an adverse or disclaimed audit result (AGSA, 2023).