CHAPTER 2 LITERATURE REVIEW

# Literature outline

The literature was used to identify sources, pressures, states and impacts driven by abandoned mines and potential policies as responses to address potential land contamination and associated risks.

## Introduction

A literature review selects relevant sources to extract, analyse, critically evaluate and synthesise existing information, ideas, findings and standpoints relating to the topic, problem statements and research questions Hart (2018). The literature review covers the origins and definitions of the topic, key ideas, strategic interactions of the ideas and research methods (Torraco, 2005:361). The drivers, pressures, state, impacts and responses (DPSIR) framework was used as a literature map to express relationships between ideas, arguments and ideas relating to the study.



Figure 2‑1: Drivers, pressures, state, impact and responses application used to map relationships between ideas in literature.

## DPSIR framework

Friend and Rapport (1991:71) highlighted that the Statistics Canada Office established the stress-response environmental statistical reporting approach in 1979 for the state of environmental reporting. Consequently, the idea evolved and developed into the DPSIR framework by the European Environment Agency in 1995 for the Dobris Assessment of the European environment (i.e., air, water and soil) (Gari *et al.*, 2015:64; Maxim *et al.*, 2009:12). The DPSIR framework is a valuable and adaptive management instrument applied to evaluate environmental problems by understanding the cause-effect relationships between human development activities and their environmental and socioeconomic concerns (Gari *et al.*, 2015:64). Maxim *et al.* (2009:12) elaborated that the causal link in the DPSIR framework starts with social and economic developments as driving forces (*D*) that exert pressures (*P*) on the environment and change the state (*S*) of the environment. This leads to impacts (*I*) on human health, ecosystem and biodiversity loss, environmental liability, affected valuable agricultural land and economic damage, which require mitigation or corrective actions in the form of responses (*R*) by responsible governance to address the *D*, *S* or *I* (Gari *et al.*, 2015:64; Maxim *et al.*, 2009:12).

The literature review focused on the history of abandoned legacy mines as *D* to establish definitions of the idea, previous operations and minerals mined. An overview was found on the characteristics and risks of the selected PTEs (As, Co, Cr, Cu, Ni, Pb, V and Zn) which are leached as *P* from mine waste with the ability to contaminate the environment (Kabata-Pendias, 2000; Levinson, 1974). This study establishes the *S* of land contamination around selected abandoned legacy mines. Therefore, a review of the guidelines for undertaking research and assessment processes on this topic is provided. Documented sources are reviewed to highlight *I* from abandoned legacy mines within the study area to address topics on land use, ecological and biodiversity attributes, arable agricultural land and environmental liability. A description of how GN. 331 from the National Environmental Management: Waste Act (Act 59 of 2008) (NEMWA) deals with norms and standards for contaminated land is provided as part of the *R*.

## Drivers of potential land contamination from abandoned mines

The world is subject to increasing demands of economic development that thrive on the increased consumption of raw materials (Holt, 2000:21). This has led to various anthropogenic activities in major sectors (e.g., agriculture, mining and smelters, industrialisation, transport and textiles) (Carré *et al.*, 2017:276; Holt, 2000:21). These activities are directly or indirectly induced by humans to influence environmental change and are known as anthropogenic processes or activities (Li *et al.*, 2019:382). Waste generated from anthropogenic activities releases contaminants into the environment that impact natural resources (i.e., land, water, air and ecosystems).

Principal sources or drivers of land contamination are linked to residue waste from mining and abandoned or uncontrolled hazardous waste sites from commercial industries (Nriagu and Pacyna, 1988:139). Mining activities and associated mine waste are of particular interest here. Generating mine waste occurs over several centuries without proper disposal approaches and constitutes a driving source of potential environmental contamination (Ledin & Pedersen, 1996:68). Ledin and Pedersen (1996:68) indicated that mine tailings and waste rock drive major contaminants of chemicals used during extraction and processing of the mineral ore. Waste rock is a low-grade overburden material removed to uncover ore deposits that cannot be processed commercially (Blowes, 1997:887). Mine tailings are residue materials generated from mineral processing (e.g., slimes, slurry, tailings, discards and plant waste) (Blowes, 1997:888; Ledin & Pedersen, 1996:68). In the selected study region, mine waste and waste rocks were generated by exploiting:

* Coal from the Emalahleni and Springbok coalfields,
* Au in the Pietersburg Greenstone Belt,
* PGMs in the northern and eastern Bushveld Complex,
* Andalusite and Mn in the eastern Bushveld Complex, and
* Asbestos for economic development that extracted raw materials.

## Potential contaminants exerting environmental pressure

Carré *et al.* (2017:276) indicated that toxic elements contribute to 60% of the contaminants discovered on land in Europe, the USA, and Australia. Other contaminants include petroleum hydrocarbons, benzene, toluene, ethylbenzene, xylene, phenols and cyanides (Carré *et al.,* 2017:276). Anthropogenic activities through extracting and consuming raw materials disturb the natural geochemical cycle and result in accumulating toxic elements in the environment (Dixit *et al.*, 2015:2192). Mining activities and improper disposal of mine waste influence the dispersion of non-biodegradable toxic elements (Wong *et al.*, 2006:3). Yabe *et al.* (2010:1258) reported that Africa including SA is faced with the challenge of PTEs disposed to the environment. These PTEs include As, Cr, Cu, Co, Pb, Ni, V and Zn which is why they were selected for this study. These elements use AMD, waste dump erosion, seepages and wind-blown dust as pathways for disposal on land.

Table 2‑1: Potentially toxic elements selected for study.

|  |  |
| --- | --- |
| **PTE(Potential Contaminants)** | **Description** |
| As | A natural element present in all soils and organic matter (Duker *et al.*, 2005:632). Levinson (1974) indicated that As is used as a pathfinder for Ag, Au, Cu and Pb-Zn deposits with an average crustal abundance of 5 ppm within the soil. It is found in association with minerals, such as pyrite, galena, sphalerite, other sulphides and apatite. Järup (2003:178) presented that contamination of natural resources (air, water and land) by As relates to two main activities. These involve the smelting of non-ferrous metals as well as mining and producing energy from fossil fuel (mostly coal). Potential land contamination by As is associated with mining and mine tailings (Järup, 2003:178). |
| Co | Co is an uncommon magnetic element with properties comparable to Fe and Ni (Barceloux & Barceloux, 1999:201). Barceloux and Barceloux (1999:203) highlighted that Co is produced as a by-product of Cu and Ni mining as it is often contained within the Ag, Cu, Fe, Pb and Ni ores in concentrations of less than 1%. The mining operations of the mentioned ore deposits expose Co into the environment. The average earth crustal abundance of Co is 25 ppm (Kabata-Pendias, 2000:306). |
| Cu | Cu is a chalcophile element and is abundant in mafic and intermediate rocks (Kabata-Pendias & Pendias, 1984:75). Kabata-Pendias (2000:106) noted that Cu is mobile in acidic environments. Cu forms simple and complex sulphides as common primary minerals. In humans, high concentrations of Cu from soil can cause stomach cancer and asthma. |
| Cr | Kabata-Pendias (2000) defined Cr as a siderophile and deposits in ultra-basic rocks. Cr is a pathfinder of chromite, Pt and other ultramafic ore deposits (Levinson, 1974). Mining chromite and Pt deposits expose Cr to the environment through waste disposal. Rowbotham *et al.* (2000:149) indicated that waste disposal activities allow Cr to enter the soil and this potentially leads to the land contamination. Levinson (1974) specified that the average crustal abundance of Cr in soils is 50 ppm. |
| Ni | Ni is both a siderophile and found in mafic-ultramafic igneous rocks and black shales in sediments (Kabata-Pendias, 2000:314). The element is mobile during weathering and coprecipitates with Fe and Mn (Kabata-Pendias & Pendias, 1984). Ni is a pathfinder for massive sulphide, platinum metal and certain U deposits with an average abundance of 30 ppm in the soils (Levinson, 1974). Mining, oil refinery, metal processing and sludge are identified as the sources that expose Ni. Genchi *et al.* (2020:1) identified cardiovascular, kidney diseases as well as lung and nasal cancers as human health issues associated with high exposure to Ni. |
| Pb | Pb is a high chalcophile with an average abundance of 15 ppm in the earth’s crust (Kabata-Pendias, 2000:210). It is found in natural parent materials, such as magmatic and ultramafic rocks as well as argillaceous and calcareous sediments. Kabata-Pendias (2000:211) indicated that Pb is hazardous to human health and animals through the food chain and soil dust inhalation. Old mining areas, the metal processing industry, waste sites and sludge have been identified as sources of Pb in the environment (Kabata-Pendias & Pendias, 1984:157; Purves, 2012:9). |
|  |  |
| V | Levinson (1974) described V as a siderophile and lithophile element. It is used as an indicator when exploring for Ag, Au, Cu and Zn in polymetallic sulphide deposits as well as Sn, Fe and phosphate in vanadiferous magnetite deposits. It has an average crustal abundance of 80 ppm in soil and is mobile during weathering depending on associated minerals (Kabata-Pendias, 2000:234). Xu *et al.* (2021:2) indicated that mining smelters, plants and processing waste accounted for concentrations of V released into the environment. |
| Zn | Based on Kabata-Pendias (2000:136), the metal industry and mining are the main sources of high Zn concentrations in the environment. Zn is soluble and available for plant uptake (Kabata-Pendias, 2000:136). The average abundance of Zn in soil is 50 ppm (Levinson, 1974). The health effects associated with Zn include anorexia and depressed immune response among others taken up through the food chain, such as fish from polluted water (Wuana & Okieimen, 2011:6). |

Abbreviations: arsenic (As), chromium (Cr), cobalt (Co), copper (Cu), gold (Au), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), platinum (Pt), potentially toxic elements (PTEs), silver (Ag), tin (Sn), uranium (U), vanadium (V), zinc (Zn)

## State of land around abandoned mines

According to Yabe *et al.* (2010:1258), land contamination caused by the leaching of toxic elements from mining activities and related industries has been reported throughout Africa as a hazard. The Department of Environmental Affairs (2012:3) stated in the 2nd South Africa Environment Outlook report that abandoned legacy mines, urbanisation into areas of previous mining and new mining developments are trends that encroach onto agricultural and water resources as well as conservation areas causing fewer effective ecosystems and loss of productive land. Muller (2020:12) specified that there are no current national and regional data regarding the extent of contaminated land in SA from mining and related industries. Therefore, this study will delineate and produce a map of potential land contamination around abandoned mines.

Several studies have been conducted, but none have focused on assessing potential land contamination in the selected region. Schoeman (2016) produced a risk map of the impact of coal mining in Emalahleni using remote sensing methods that identified areas of coal combustion, subsidence, potential AMD and air pollution. Sibiya (2019) conducted research that determined the potential acid-base generation and concentration of PTEs affecting the water quality around abandoned mines in the Barberton Greenstone Belt. Sibiya (2019) revealed that abandoned mine dumps leach PTEs into the environment through wind and water seepages, which affects water quality and causes land contamination. Coetzee *et al.* (2006), Oelofse *et al.* (2007) and McCarthy (2011) indicated that abandoned mines in the Witwatersrand are left in a state of generating AMD from previous underground workings that flood to the surface. Furthermore, the characterisation of gold mine dumps revealed the dispersion of PTEs into natural resources (waterbodies and soil).

## Impact of abandoned mines

Balkau (1999:5) emphasised that countries with a history of mining are susceptible to environmental, social and economic challenges. Countries such as the USA, SA, Brazil, Canada, France, Germany and China are faced with financial and rehabilitation burdens from previous mining activities that commenced without strict environmental legislation and enforcement (Balkau, 1999:4; DEA, 2012:4; Sibiya, 2019:25). The application of DPSIR shows how contamination of land caused by abandoned mines influences and threatens environmental, social and economic aspects.

### Environmental impact

The environmental impact of abandoned mines is manifested in its physical and chemical properties. The physical environmental impacts include (Balkau, 1999:4; Mhlongo, 2022:227; Sibiya, 2019:25):

* Open mine entries (shafts and adits);
* Surface pits or excavations (with high walls and often filled with water);
* Old mine infrastructure;
* Subsidence and sinkholes; as well as
* Unrehabilitated tailings dumps.

All physical environmental impacts are a concern for post-closure land use. For instance, changes in the landscape of sinkholes within mining properties and neighbouring farms caused by abandoned mines are common in SA (Isiaka *et al.*, 2019:1531). Sinkholes can be natural or induced (Keiller, 2010:4). In SA, natural sinkholes are caused by weathered dolomite and dolomitic limestone which cause instability (Isiaka *et al.*, 2019:1531; Keiller, 2010:4). Induced sinkholes are caused by the dewatering of underground mine workings and extracting groundwater in some areas (Moshodi *et al.*, 2016:2).

Chemical environmental impacts include coal combustion, AMD, water pollution, land pollution, and seepage of toxic elements from mine dumps, slimes and tailings dams (Coetzee *et al.*, 2006; Oelofse *et al.*, 2007). For example, in 2012, the population of Carolina in the Mpumalanga province (17 000 people) were affected by an undrinkable tap water supply contaminated by mine water due to AMD, which became evident from coal mining (Tempelhoff *et al.*, 2014:81). Based on Naidoo (2017:51), the tap water was contaminated with sulphates, As, Co, Cu, Ni, Pb and Zn.

### Economic impact

Some countries have identified the economic impact of contaminated land from abandoned mine sites and have initiated financial approaches to address global challenges. Superfund by the USA is an example of a financial strategy which was introduced to account for contaminated sites of mining (Fogleman, 2014:52). In SA, the national government noticed a weak regulatory system regarding mining responsibility and established the Fanie Botha Accord (1975) between the Chamber of Mines and the Minister of Water Affairs. This meant that the government had to take full accountability for the rehabilitation of closed mines before 1976 (Cornelissen *et al.*, 2019:1; Munnik *et al.*, 2009:8). This led to financial and economic burdens, as environmental impacts (e.g., AMD and asbestos from historical mining) are still evident over long periods after mining ceases. To date, the government is left with the environmental liability and responsibility to rehabilitate approximately 6 000 abandoned mines.

### Social impact

Land coverage by waste dumps and tailings from mining activities should be classified as a threat to human health, safety and development as it poses constraints to urban development (Mahao, 2017:38). For example, Van Breugel *et al.* (2019:2) reported that in 2001, sites where coal discards were disposed resulted in 4 011 ha of unusable land. This indicated the social impact of abandoned mines across SA. Similar findings were made by Isiaka *et al.* (2019:1531) that sinkholes cost SA more than ZAR 1 billion and led to the deaths of 38 people over a 50-year period. The Merafong City Local Municipality is a good case for the environmental hazard of sinkholes linked with social impacts, especially in the Khutsong township. Moshodi *et al.* (2016:2) noted that the business sector of Khutsong township collapsed into a sinkhole triggering infrastructural damage, financial loss, unstable surface ground for neighbouring farms and damage to residential buildings. This influenced social impacts, such as loss of job creation, income to sustain families, a threat to food security and the right to peaceful homes without fear of another sinkhole.

### Health impact

Nkosi *et al.* (2021:1) noted that communities residing near mine dumps were subjected to wind-blown dust that caused air pollution which contained toxic elements that affected residents’ health. Furthermore, Nkosi *et al.* (2021) discovered that dispersed toxic elements from wind-blown dust caused high blood pressure in elderly residents near mine dumps. Okereafor *et al.* (2020:13) discovered a high percentage of respiratory and ocular symptoms among residents living near gold mine dumps.

## Responses toward contaminated land

Responses to waste management in SA began with the enactment of an appropriate legislative framework over several years. Godfrey and Oelofse (2017:2) highlighted that major changes came through the Environment Conservation Act (Act 73 of 1989) (ECA) which provided the initial waste definition and requirements for waste management. However, the ECA did not regulate 80% of the volume of mine waste disposed of on land (Alberts *et al.*, 2018:1088), and has since been repealed by the National Heritage Resources Act (Act 25 of 1999). This section describes the National Framework for the Management of Contaminated Land as a response measure.

### Constitution of the Republic of SA

The Constitution introduced sustainable development, human health and well-being as principles that govern environmental legislation through environmental rights. The rights in Section 24(a) of the Constitution state that: “Everyone has to an environment that is not harmful to their health or well-being”. Section 24(b) of the Constitution promotes the conservation and protection of the environment and undertakes ecologically-sustainable development through all future developments.

### MPRDA

The Mineral and Petroleum Resources and Development Act (Act 28 of 2002) (MPRDA) provides provisions for “equitable access to and sustainable development of the nation’s mineral and petroleum resources, and matters connected therewith”. Regulation 56(d) and (e) of the GNR527 (under MPRDA) requires that impact on the land be identified and quantified, and that the land be rehabilitated per the National Environmental Management Act (Act 107 of 1998) (NEMA) and related regulations. Section 43(1A)(c) of NEMA (under the MPRDA) provides the Minister of xxx licensing authority regarding waste management related to residue deposits and stockpiles from mining activities. The MPRDA applies to abandoned mines and related mine waste which makes it relevant and applicable to this study.

### NWA

The National Water Act (Act 36 of 1998) (NWA) introduced Sections 21(g) and (h) to manage potential effluent leachate contamination from waste disposal sites. The main focus of these sections was to protect the surface and groundwater from contamination by acid-generating waste. However, NWA does not govern contaminated land. The NWA identifies potential pathways and pressures that are exerted into the environment, such as AMD and seepage from slimes or tailings dams. Surface water bodies as potential receptors for the migration of toxic elements through potentially contaminated land will be identified.

### NEMA

NEMA was introduced to affect constitutional environmental rights. Furthermore, this established environmental management principles (Section 2 of NEMA) to guide decision-making and manage human activities in the environment (Oosthuizen *et al.*, 2018:129). Other sections of NEMA focus on corporative governance and procedures but will not be covered by this study. NEMA places requirements on listed activities to apply for environmental authorisation (EA) in Section 24 before commencing with planned development. The EA obliges the applicant to perform an environmental impact assessment. These procedures aim to ensure that the development of listed activities accounts for all actions through an environmental management tool called the Environmental Management Programme described in Section 24N. NEMA made a provision to administer other environmental management laws called specific environmental management acts (SEMAs). This led to the development of SEMAs, such as NEMWA and the National Environmental Management: Protected Areas Act (Act 57 of 2003) (NEMPAA) which form an important part of this study. Overall, NEMA oversees all listed activities proposed for the environment and places responsibility on contaminated land and mitigation measures through Section 28 which deals with the duty of care.

### NEMPAA

NEMPAA was included here to identify land-use competition among all national, provincial and local protected areas against abandoned mines as potential receptors of possible illegal mining on such sites. NEMPAA’s aim is “to provide for the protection and conservation of ecologically viable areas representative of South Africa's biological diversity and its natural landscapes and seascapes” (source). The Act provides a national register for all protected areas.

### NEMWA

NEMWA was promulgated in 2009 and governs waste management in SA. Other parts of NEMWA became operational later, such as Part 8 of Chapter 4 which deals with contaminated land. Section 1 of NEMWA concerning Part 8 states that:

contaminated is defined as the presence in or under any land, site, buildings or structures of a substance or micro-organism above the concentration that is normally present in or under that land, which substance or micro-organism directly or indirectly affects or may affect the quality of soil or the environment adversely.

Regulations for Part 8, Section 35, are classified as retrospective for assessing contamination that occurred before NEMWA’s commencement, arose or is likely to arise from actual activity, including those that have already been declared as contaminated land in Section 38. This has led to the publication of the Framework for the Management of Contaminated Land which provides norms and standards in Section 7(2)(d) of NEMWA for assessing contaminated land and remediation. This allowed for assessing potential land contamination around the abandoned mines selected for this study.

### SPLUMA

Government Notice Regulation 1590 of the MPRDA (i.e., the Housing and Living Conditions Standard for the Minerals Industry, 2019), suggests that previous mining areas can be used for residential development. Spatial planning and land-use management in SA are managed by the Spatial Planning and Land Use Management Act (Act 16 of 2013) (SPLUMA). SPLUMA places the management of local land use matters in the hands of the local government (mostly municipalities). In Section 24, SPLUMA requires that each local municipality prepare, adopt and implement a land-use scheme (LUS) in line with the existing Municipal Spatial Development Framework. Land use is determined based on the jurisdiction of the municipal area in the Local Government: Municipal Demarcation Act (Act No. 27 of 1998). A LUS is a development tool that allows or restricts certain types of land use to certain geographic areas to exercise control over the spatial use of the land (Fourie, 2019). Therefore, to understand what alternative land uses can be applied for areas which have been previously classified for mining use, prospecting rights and mining permits are answered by LUS classes from each municipality under investigation.

## Chapter summary

This chapter provided the driving forces that lead to potential contamination and outlined contaminants from abandoned mines. Previous studies have delineated the impacts and gaps in the literature that led to this study. Finally, responses to land contamination in the form of policies and legislation were provided.