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Research Article

Artisanal and small-scale mining activities as post-mining land use in abandoned mine sites: a case of Giyani and Musina areas, Limpopo Province of South Africa

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Abstract

South Africa has many artisanal and small-scale mining (ASM) activities that some are registered and others informal and illegal. This paper presents an overview of ASM operations in the vicinity of abandoned mine sites found in Giyani and Musina areas, Limpopo Provine of South Africa. It looks at the mining processes, environmental problems, and health and safety risks of ASM in the area. It also provides a discussion of practical ways of dealing with the problems of artisanal and small-scale mining operations in a harmonized way with the rehabilitation of the abandoned mine sites. The exploitation of waste rock dumps for aggregate production in Musina demonstrated that formalized ASM activities could be the best alternative uses of the abandoned mine sites. However, artisanal gold mining around Giyani revealed the health and safety risks and environmental problems of these operations. The artisanal gold mining activities worsened the health and safety and the environmental problems of the abandoned mine sites. Therefore, this paper recommends that the efforts of coming up with strategies to formalize and regulate artisanal mining in South Africa be deepened for these activities to be acceptable as sustainable as post-mining land-uses in abandoned mines.

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Introduction

Artisanal and small-scale mining activities are known and recognized in many countries throughout the world. In South Africa, this sector was first recognized in 1994. It is divided into three categories, namely, (i) registered and legal operations, (ii) informal operations, and (iii) artisanal illegal operations (also known as Zama-Zamas) (Ledwaba, 2017). Artisanal and small-scale mining activities are used to exploit different commodities that the most common is gold. However, in South Africa, it is also used in exploiting alluvial diamonds, clay, sand, and gravel, as well as natural stones. According to Zvarivadza and Nhleko (2018), there is no universally accepted definition for ASM. Thus, they are defined differently from one country to the other (Hilson, 2002). The term "artisanal mining" is used to refer to the smallest and simplest mining operations which use rudimentary tools, while; "small-scale mining" refers to mining activities that use basic mining and processing techniques such as drilling and blasting, mechanical loading, and hauling as well as processing (Ruppercht, 2017).

In South Africa, many artisanal and small-scale mining activities are conducted around the areas of known deposits that include abandoned mine sites

(Mhlongo et al., 2019a). The issue regarding this is that mining operations are sometimes closed or abandoned because of financial and economic problems, political instability, and social conflicts. Not due to the depletion of the deposit. Consequently, artisanal and small-scale miners go to these sites for mining of the remnants of the deposits that would have been left behind by previous bigger mining companies. These mining operations are characterized by devastating environmental impacts and health and safety hazards (Phiri et al., 2015). They are associated with different social ills. An example of these ills includes the abuse of substances and alcohol, child labor, and prostitution (that results in to spread of HIV and AIDS) (Hilson, 2002). To effectively deal with these and other problems of ASM in the country, it is important that a national strategy of formalizing ASM operations in developed. Such mostly require a thorough analysis of the local context under which these activities are practiced in the country. This paper details the issues of artisanal and small-scale mining carry out in different abandoned mine sites in the areas of Giyani and Musina (Limpopo Province of South Africa). It looks at the processes of mining and mineral processing, their environmental problems, and the health and safety risks of the ASM operations in the study area. It also discusses some of the practical intervention strategies for dealing with the problems of ASM in the abandoned mine sites to make them sustainable post-mining land uses.

The description of the case study

The Giyani area is found in the eastern part of the Limpopo Province, while Musina is found far north of the Province towards the Beitbridge Border Gate to Zimbabwe. Musina has five documented abandoned copper mine sites, such as Mesina, Campbell, Spence, Harper, and Artonvilla. These mines are distributed along the northeast-southwest striking Messina Fault. According to Beale (1985) and Chinoda et al. (2009), the orebodies of these mines were hosted by gneisses of different compositions (See Figure 1a).

These gneisses were explained by Cairncross (1991) to be in the form of a structurally complex suite of lithologies that resulted from multiple folding and metamorphic recrystallization. It is important to mention that the 85 years-long histories of copper mining in the area of Musina ended in 1991 with the closure of No. 5 Shaft of Mesina Mine (Wilson, 1998). Abandoned gold mine sites are found in different parts of the Giyani Greenstone Belt (GGB). These mines are Klein Letaba, Fumani, Frankie, New Union (also known as Golden Osprey), Birthday, and Louis Moore shown in Figure 1b.

According to Ward and Wilson (1998), the gold mineralization in the GGB is associated with quartz veins that have minor sulfide development, banded iron formation (BIF), quartz and sulfide replacement veins, and carbon veins. Large-scale mining operations in the belt ceased in the early 1990s (Steenkamp and Clark-Mostart, 2012). The other abandoned mine site used in this study is the Nyala Magnesite Mine (see Figure 1c). This mine is found in the vicinity of the village of Zwigodini situated approximately 100km southeast of Musina Town. The magnesite deposit at this mine was reported by Strydom (1998) to be hosted by metamorphosed shales and feldspathic sandstones of the Ecca Group. In this mine, magnesite was mined by an open-pit method conducted up to the estimated maximum depth of 23 m (Mhlongo and Amponsah-Dacosta, 2015; Strydom, 1998).

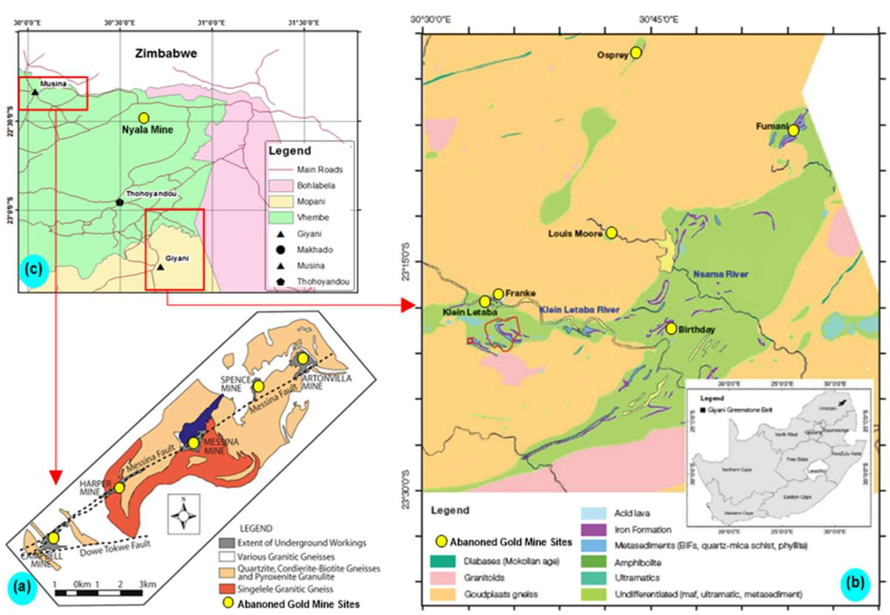

Figure 1. The location of abandoned mine sites in Musina (a) and Giyani (b) areas. The Nyala Mine is shown in (c) (Billay et al., 2014; Chaumba et al., 2016; Mhlongo et al., 2018a).

Literature review: abandoned mines and ASM in South Africa

The Mineral and Petroleum Resources Development Act (Act No. 28 of 2002) of South Africa defines abandoned mines as those mines in which a closure certificate has not been issued; no part can be traced to assume responsibilities; the government may provide funds for their rehabilitation. The official term used to refer to abandoned mines in South Africa is Derelict and Ownerless Mines (D&O). There are about 6000 documented D&O mines in South Africa. Most of them possess different hazards to the environment, people, and animals. The program of rehabilitating abandoned mines in South Africa has been for many years focused on dealing with asbestos mines that present high health risks (Mhlongo and Amponsah-Dacosta, 2016; Cornelissen et al., 2019). However, the attempt of closing some of the dangerous mine shafts in different parts of the country (for example, Witwatersrand Basin, Barberton and Giyani Greenstone Belt, Musina, etc.) were also undertaken (Mhlongo and Amponsah-Dacosta, 2016; Mhlongo et al., 2018a; Mhlongo et al., 2019a).

On many occasions, abandoned mine sites in South Africa are found within the communities or settlements that are informal. Some of these communities are established on these sites after closure or abandonment of the mining operations that make land available to informal occupants. Moreover, in the mining towns, the development of informal settlements on abandoned mine sites is somehow encouraged by the shortage of land for housing purposes (Olalde, 2017). It is important to note that active mines are also responsible for the informal settlements mushrooming in many mining towns. Difficulties of getting affordable accommodation near the mines are also responsible for some of the mine workers residing in informal settlements near the mines (Marais et al., 2018).

In general, informal settlements are characterized by poor living conditions and livelihoods that can be described as poor. They are dominated by social ills such as drugs and alcohol abuse (responsible for increased crime incidences and disorder, gangsterism, and prostitution). They also result in increased HIV and AIDS infections (Winde and Strach, 2010). The poor living conditions in these settlements are also responsible for the dwellers suffering from different chronic illnesses that are worsened by their exposure to health hazards possessed by the abandoned mine sites where the informal settlements are developed (Liefferink, 2011). These include exposure to radioactive waste, acid mine drainage, toxic metals pollution, and the problems of spontaneous combustion of coal in old mines. Based on these issues and the lack of alternative job opportunities that prevail in abandoned mines host communities, many people in these communities turn to participate in dangerous and illegal artisanal mining activities in abandoned underground mine workings.

Because some of the people in the host communities would have worked in these mines before their closure and have enough knowledge of mining makes it easy for them to return to underground mine workings for illegal artisanal mining. Currently, South Africa has about 30000 illegal miners operating in abandoned mine sites (Snell, 2019). Many artisanal miners get killed underground by rockfalls, inhalation of mine gases, and drowning in water filling the underground mine voids. They are also killed in crimes and gangsterism activities that are associated with artisanal and illegal mining activities. According to Sieff (2016), in the Witwatersrand Basin alone, one illegal or artisanal miner die in abandoned mine shafts weekly.

There are also cases of well-established formalized small-scale mining operations around the abandoned mine sites in South Africa. These include the mining of rock waste dumps for rock aggregate production in the South Deep Gold Mine and Musina Copper mines (South African National Roads Agency SOC Ltd, 2013), re-mining of gold tailings for gold recovery in the Witwatersrand (Fleming et al., 2010), and mining of gold tailings in the Witwatersrand Basin for use as sand replacement in the making of cement bricks and/or blocks (Malatse and Ndlovu, 2015). In general, the mining and reuses of old mine waste are impotent strategies for dealing with such wastes and their problems (Aznar-Sánchez et al. 2018).

Materials and Methods

The methodology used in this study involved carrying out the site characterization of artisanal and small-scale mining activities conducted in different abandoned mine sites in Giyani and Musina areas, Limpopo Province of South Africa. The fieldwork involved visiting 12 abandoned mine sites in the study area. The list of these mines is in Table 1. This fieldwork involved identifying the nature of artisanal and small-scale mining activities practiced in such a site. It should be noted that the studied abandoned mine sites during their operations mined copper, magnesite, and gold. The field description of ASM activities in these mines looked at the nature of the material targeted for mining, the mining, and mineral processing procedure (including the type and level of equipment used). The fieldwork also involved documenting the potential environmental and the health and safety issues of ASM in the study area. To have a clear understanding of the problems and concerns of these operations around the abandoned mine sites. Informal discussions between the researcher and some of the artisanal and small-scale miners were conducted. This aimed at getting a deeper understanding of the problems and concerns of ASM operations in the study area.

Table 1. Details of the abandoned mine sites studied for the characterization of their associated of ASM activities.

No	Mine site	Commodity mines	Mining methods used	Registration status	Comments of the status of ASM
1.	Klein Letaba	Gold	Underground	X	▪ Artisanal gold mining conducted on the surface and underground.
2.	Louis Moore	Gold	Underground	X	▪ Artisanal gold mining conducted on the surface and underground.
3.	Frankie	Gold	Surface and underground	X	▪ Artisanal gold mining conducted on the surface
4.	Birthday	Gold	Underground	X	▪ Artisanal gold mining conducted on the surface and underground.
5.	New Union	Gold	Underground	X	▪ Artisanal gold mining conducted on the surface
6.	Fumani	Gold	Underground	X	▪ No mining due to restricted access to the site
7	Nyala	Magnesite	Surface	X	▪ Informal remining of magnesite tailings for different uses
8.	Messina	Copper	Underground	X	▪ Informal remining of copper tailings for different purpose
				√	▪ Remining of waste rocks for aggregate production
9.	Campbell	Copper	Underground	√	▪ Remining of waste rocks for aggregate production
10.	Artonvilla	Copper	Underground	√	▪ Remining of waste rocks for aggregate production
11.	Spence	Copper	Underground	—	▪ No evidence of ASM
12.	Harper	Copper	Underground	—	▪ No evidence of ASM

Note: X infomal and unregistered operation, √ registered and formal operations.

The field description of ASM operations was followed by document analysis. A critical review of the documents that discuss ASM and the problems of abandoned mine sites in the study area was done. The details of such documents are in Table 2 and Table 3. This review helped identify cases where ASM worsened the problems of the abandoned mines. It also demonstrated situations where ASM help to address some of the issues of the abandoned mine sites. It is important to note that ASM and the abandoned mines in the study area remain understudied. Therefore, few studies of ASM and abandoned mine sites conducted outside the study were also reviewed.

Table 2. The main articles reviewed to understand the issues of ASM in the study area.

No	Author(s)	Article type	Specific Study Area	Typology
1.	Steenkamp and Clark-Mostert (2012)	Conference paper	The whole of the GGB	Case study
2.	Sithole (2016)	Mini-dissertation	Klein Letaba and Louis Moore mines	Case study
3.	Rembuluwani (2016)	Mini-dissertation	The whole of Vhembe District	Case study
4.	Magodi (2017)	Dissertation	Klein Letaba and Louis Moore mines	Case study
5.	Mhlongo et al. (2018b)	Conference paper	Louis Moore	Case study
6.	Mhlongo et al. (2019a)	Journal paper	Louis Moore	Case study

Table 3. The main articles reviewed to understand the problems of abandoned mine sites in the study area.

No	Author(s)	Article type	Specific Study Area	Typology
1.	Mitileni et al. (2011)	Conference paper	New Union mine	Case study
2.	Mhlongo et al. (2013)	Journal paper	Nyala mine	Methodological
3.	Sibanda et al. (2013)	Journal paper	Nyala mine	Case study
4.	Rembuluwani et al. (2014)	Conference paper	New Union mine	Case study
5.	Muzerengi (2015)	Conference paper	Louis Moore	Case study
6.	Gitari et al. (2018)	Journal paper	Messina mine	Methodological
7.	Mhlongo et al. (2018a)	Journal paper	Giyani and Musina areas	Methodological
8.	Mhlongo et al. (2019b)	Journal paper	Giyani and Musina areas	Methodological
9.	Sigxashe (2020)	Dissertation	Klein Letaba and Louis Moore mines	Methodological

Results

Overview of ASM in abandoned mines of the areas of Giyani and Musina

In Giyani and Musina areas, artisanal and small-scale mining activities are conducted in different abandoned mine sites. Artisanal gold mining (AGM) is conducted in abandoned gold mine sites found in the Giyani Greenstone Belt. Registered and informal small-scale mining operations focused on exploiting waste dumps for different purposes are practiced around the abandoned copper and magnesite mines. The level at which the three types of ASM activities are practiced in the study area is shown in Figure 2. In this case, artisanal mining is dominant (46%). Followed by registered and then informal small-scale mining operations that account for 27% and 9%, respectively. Two mine sites (i.e., Harper Copper Mine in Musina and Fumani Gold Mine in Giyani) had no evidence of ASM activities (see Figure 2). This is because there are no waste rocks or tailing dumps targeted for mining and use in aggregate production in Harper Mine. The Fumani gold mine site is fenced and secured from artisanal and small-scale miners. The sections below describe artisanal and small-scale mining activities conducted in the Giyani and Musina areas of abandoned mine sites.

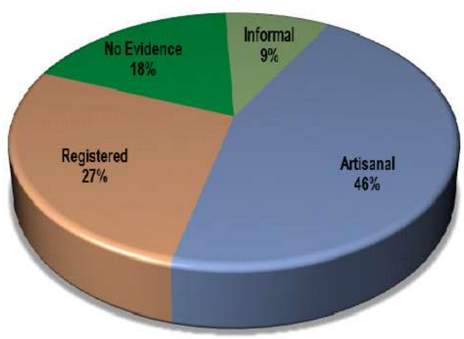

Figure 2. Practices of different artisanal and small-scale mining activities in Giyani and Musina areas.

Registered small-scale mining

This type of small-scale mining activity is practiced by two companies that operate rock aggregate production plants in the abandoned Mesina and Campbell copper mine sites. The aggregate production in these sites is carried out in two ways, although the final products are the same. In Campbell mine site, the aggregate production operations involve loading, transportation, and crushing of waste rocks generated by earlier copper mining at abandoned Artonvilla Mine (see Figure 3a). The process of aggregate production at Mesina Mine makes use of a mobile crusher that is equipped with screens that sort the products of the crushing process into different sizes (see Figure 3b). In this case, the mobile crusher is positioned at the base of the waste rock dump, and appropriate rocks are selected and fed into the crusher through the hopper. The waste rocks mined in these operations comprised dominantly of different metamorphic rocks (mostly the quartzites and gneisses) of the basal Mount Dowe Formation of the Beit Bridge Complex. These rocks hosted the copper deposits mined by different operations in the region (Wilson, 1998). According to authors like Langer and Knepper (1995) and Leroy et al. (2017), metamorphic rocks such as gneisses produces an aggregate of comparable quality to that produced from the crushing of coarse-grained igneous rocks. This suggests that the waste rock dumps used for rock aggregate production in abandoned mines of the Musina area are suitable for the purpose.

In the stone crushing operations at Campbell Mine, the mining of waste rocks is done using the front-end-loader (FEL) that loads the rocks into the dump trucks (10m³ size dump trucks). The rocks are then transported from the dumps found at the abandoned Artonvilla Mine to the crushing plant situated about 16km away at Campbell Mine. At the crushing plant, the rocks are first passed through the magnetic drum that removes foreign steel objects from the waste rock. Once such objects are removed, the rocks are then passed through the vibrating screen that sorts the material into different sizes before it is taken for primary crushing. The different oversize materials produced from the primary crusher are transported using conveyor belts to the secondary crushing area, while; material of the desired size is conveyed to the stockpiles designated for them. The aggregate production operations from the waste rocks dump found at the abandoned copper mine sites (Musina Town) are fully mechanized. The production operations in this mine can be summarized as illustrated in Figure 3a and b.

Informal small-scale mining

These are mining activities that take place outside the legal framework (Dreschler, 2001). Informal type of small-scale mining is practiced at Nyala Mine and Mesina Copper Mine. In these sites, the community partakes in mining abandoned copper tailings and magnesite tailings for different uses. The study by Sibanda et al. (2013) showed that the magnesite tailings from Nyala Mine could replace river sand in the construction industry and making cement blocks of bricks. Also, these tailings can be used to fill roads and foundations of buildings. Similarly, Gitari et al. (2018), in their study of the copper tailings from Mesina Mine, revealed that the chemical composition of the copper tailings from Mesina Mine does not pose any health risks when used in the construction industry. The exploitation of these materials in the study area is conducted haphazardly using a front-end-loader (depending on the availability) or the basic peak and shovels equipment. The tailings are loaded used these pieces of equipment in trucks of different capacities from the nearby communities. The sections of magnesite (a) and copper (b) tailings that are mined out are shown in Figure 4.

Figure 3. General flow of aggregate production operations at abandoned Campbell (a) and Mesina (b) copper mines.

Figure 4. Illustration of the section of the magnesite (a) and copper (b) tailings that is currently being mined for different purposes at Nyala and Musina mines, respectively.

Artisanal mining

Artisanal mining is practiced in almost all abandoned gold mines that are scattered across the Giyani Greenstone Belt. The operations in artisanal gold mining (AGM) starts with the excavation of gold-bearing sediments around the abandoned mine sites. This is followed by the sluicing of the gold-bearing material that produces a gold concentrate appropriate for further gold recovery processes. The mining is done using rudimentary tools (peak and shovels) to dig sediments believed to be bearing gold in different parts of the abandoned mine site. The most targeted areas are old and redundant mineral processing sites, foundations of old mine buildings and concrete mounting stands, and sometimes around and in the abandoned underground mine shafts. Digging of gold-bearing sediments on the leaves behind an extensively degraded land with dangerous shallow pits. The material is mined and sieved inside the pits (see Figure 5a). The sieving is done to remove unwanted gravel from the gold-bearing finer sediments. The gravel material generated from the in-pit sieving process constitutes the only waste produced by artisanal gold mining activities. This waste is found in different parts of the abandoned gold mines in the Giyani Greenstone Belt. Haphazard digging around the abandoned mine sites does not only degrade the land. It also contributes to deforestation and disruption of the soil structure (Mhlongo et al., 2018b). This is because the digging process exposes the roots of the trees and shrubs growing in the abandoned mine landscapes, thus; leading to the drying up and later falling (see Figure 5b). Sometimes the trees are deliberately cut down to clear the land for artisanal mining activities. Moreover, the gravel produced from the sieved of gold-bearing sediments gets scattered throughout the mined-out areas that result in such areas having poor soil structure to support the easy growth of vegetation. This situation is shown in Figure 5c.

The finer gold-bearing material is filled in 12.5 kg (40 x 60 cm) bags that are then piled in clusters of

20 (see Figure 5d) and sold to customers who recover gold (per 20 bags) from the material away from the mining site (Mhlongo et al., 2019a). In other situations, the artisanal miners use old underground mine shafts to gain access to underground mine workings and mine the remnants of the deposit found along the mine tunnels. This practice is common in inclined mine shafts where the miners can easily walk down the shaft to access underground mine workings. The steps in inclined shafts also make it easier for the miners to bring the bags of gold-bearing material to the surface (Figure 5e). This dangerous undertaking of artisanal miners was reported to have been responsible for the death of two artisanal miners in the area and are also known in other parts of South Africa where these activities conducted around the abandoned mine sites (such as in the Witwatersrand basin, Barberton Greenstone Belt, etc.) (de Bruyn, 2018).

Some of the material mined in abandoned mine sites is processed around the mine sites (depending on water availability) or in nearby rivers through the sluicing process. Wherever the artisanal gold miners find it easy to access water, they build sluicing tables or boxes of 10°-15°slope angle (Steenkamp and Clark-Mastert, 2012) for recovery of free gold from the material extracted from the abandoned mine sites. As a result of this, sluicing areas like the ones shown in Figure 5a and Figure 5b are respectively found all over the landscapes of abandoned mine sites and along the banks of the river or the dry river channels. The major rivers in the Giyani area that are seriously affected by these activities are Nsami and Klein Letaba. The building of sluicing sites along the river banks and channels is associated with siltation of the river, pollution of both river water and sediments by toxic metals. They also lead to the alteration of the river morphology (Mhlongo et al., 2018b). For example, the study by Magodi (2017) showed that material excavated by artisanal miners from the abandoned mines and taken for sluicing along the Nsami and Klein Letaba rivers had concentrations of As, Cr, Co, Cu, Ni, Pb, and Zn that were above the recommended limits in soils[1]. Similarly, the study conducted by Muzerengi (2015) also reported high concentrations of Ni, Co, Zn, As, and Cr in soils around Louis Moore Mine. These metals are generally found in minerals such as chalcopyrite (CuFeS2), sphalerite (ZnS), arsenopyrite (FeAsS), and galena (PbS) that are associated with gold mineralization in most goldfields (PbS) (Garcia-Lorenzo et al., 2012; Fashola et al., 2016). The concentration of toxic metals in sluicing sites was also reported by Sithole (2016) and Magodi (2017) to surpass the recommended levels in river sediments[2].

Figure 5. (a) is an illustration of artisanal gold mining activities (Mhlongo et al., 2019a), (b) show the effect of the mining process on trees, (c) show the scattered gravel waste on mined out areas, (d) is the bags of gold bearing sediments ready for transported to the clients, and (e) show the bags of material coming from underground through the inclined shafts.

[1] South African Soil Quality Guidelines, World Health Organization Soil Quality Guidelines

[2] World Health Organization Sediment Quality Guidelines, United States Environmental Protection Agency Sediment Quality Guidelines

Figure 6. The illustration of sluicing sites found around the landscapes of abandoned mines (a), and the sluicing area along the channels of the Nsami River in the Giyani Greenstone Belt (b).

Environmental problems and health and safety risks of ASM

The ASM activities in abandoned mines around Giyani and Musina areas are dominated by artisanal gold mining. The factors contributing to many people getting involved in ASM activities have been extensively researched. These are related to poverty, lack of job opportunities, and lack of income (Arah, 2015; Zvarivadza and Nhleko, 2018). The work by reseachers like Otamonga and Potéa (2020) showed that ASM in abandoned mines plays an important role in the livelihood of people who are involved in these activities. The demand for building material and the ready availability of mine waste (i.e., waste rocks and tailings dumps) with the properties that are meet this demand was the main reason for the establishment of both registered and informal small-scale operations in abandoned copper and magnesite mines of Musina.

The exploitation of mine waste found in abandoned mine sites contributes to removing these wastes from the abandoned mines. The reuse of waste rocks in rock aggregate production also creates new formal job opportunities in the area. Although the reuse of mine waste is still not that common, such practice is among the most preferred options for dealing with the large volumes of mine waste dumps at closed mine (Lottermoser, 2011; Matinde et al., 2018; Tayebi-Khorami et al., 2019;). The activities of production of aggregate by crushing waste rocks from historic mining is generally attractive. This is because in the crushing the waste rocks, the drilling and blasting operations that are done in quarries where the fragmentation of the bedrock to produce sizable stones for crushing is necessary are avoided. Consequently, the occupational health and safety, and environmental problems of drilling and blasting operations, are eliminated. Some of the problems of drilling and blasting activities are the generation of dust, noise, ground vibration, and fly rocks (Drew et al., 2002). They also include slope instability, land degradation, and visual and landscape impacts. These impacts affect the quality of the land of the quarries (Drew et al., 2002; Degan et al., 2015; Tsolaki-Fiaka et al., 2018). The only undesirable health and safety, and environmental issues of stone crushing in the Musina area, are dust and noise. These are both generated by the crushing and screening process and equipment movement around the site. According to Degan et al. (2015), dust (especially the airborne PM10 dust) constitutes a serious health and safety management and environmental problem of any stone aggregate production project. Dust is generated from crushing and sieving or screening stages of aggregate production. Generally, it decreases with the increasing distance from these operations (Rembuluwani, 2016; Sairanen et al., 2018). These operations are also the source of noise generated by stone aggregate production activities. According to Kosala and Stepien (2016), the spread of noise from stone aggregate production operations depends on the landscape where the quarry and crushing plant is located. In this case, the noise from aggregate quarries and crushing plants in higher altitudes spread over a longer area than those in lower altitudes. In the study area, these problems are expected to affect those working around the stone crushing plant. This is because the crushing plants are away from the communities. The workers can protect themselves from the dust through the use of appropriate personal protective equipment. This will reduce the risk of the workers suffering from dust-related illnesses such as skin and eye problems, respiratory diseases (including silicosis), and other allergic reactions (Lira et al., 2012).

Artisanal mining had more problems than both registered and informal small-scale mining operations. The artisanal mining process was extensively contributing to land degradation. They also expose many people (including women and children) to several health and safety risks that include those presented by the abandoned mine sites themselves. For example, as shown in Figure 7, women were cooking around the mining site while their children play around. Moreover, a case of two miners who died inside inclined disused mine shafts in Louis Moore Mine was reported by de Bruyn (2018). The process of washing gold-bearing material on sluicing tables built along the rivers presented different environmental problems. This is because these activities contribute to river saltation and alternation of the river morphology or regime. These may have devastating effects on downstream uses of the river water. The sluicing activities along the Nsami River, pollution caused by these activities can affect the Nsami Dam found about 9 km downstream of the sluicing area. The building and sluicing of material along the rivers also increase the turbidity level of the river water. This turns to reduce the penetration of light in the water affects the physical aquatic habitat (Macdonald et al., 2014; Ali et al., 2017). The general consequence of this is the reduction in the population of the aquatic organisms in the river. The accumulation of sediments from sluicing in river channels also clog the channels and divert the river course. This can be the typical demonstration of the extent to which artisanal gold mining results in high levels of saltation, sedimentation, and alteration of the river morphology. These problems are worsened by that the miners move their sluicing sites from one location to another along the river, depending on the availability of water in the river channels (Steenkamp and Clark-Mostert, 2012). The environmental problems of artisanal gold mining in abandoned mine sites in the Giyani area are summarized in Figure 8.

Figure 7. Women cooking and children playing around the artisanal gold mining site, Louis Moore Mine.

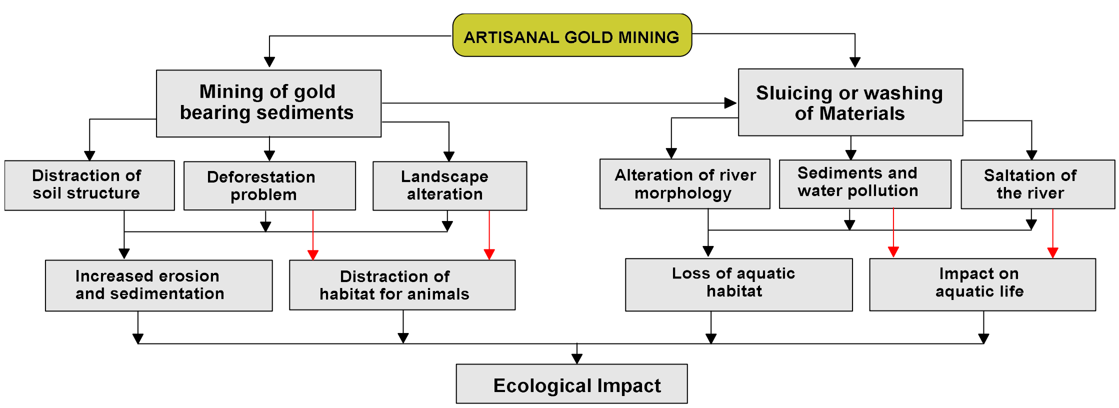

Figure 8. A summary of environmental impact of artisanal gold mining activities in the Giyani Greenstone Belt.

Discussion

ASM are important activities, especially in rural communities. They are considered significant nonfarm income earnings in most rural communities, especially in most African countries. According to Hilson and Maconachie (2017), these activities are poverty-driven as they are dominated by poor people with almost no alternative employment options. The abandonment of mines also creates conditions that encourage people to engage in ASM activities. This is because sudden closure of the mines results in the loss of jobs that leave many families without an income. Attempts to suppress artisanal mining activities to eliminate their risk has been a challenge. This situation was seen in the Giyani area and is common in other abandoned gold mine sites in other parts of South Africa. This makes it necessary that efforts of making artisanal and small-scale mining activities formal and sustainable are continued. Different scholars (e.g., Hinton et al., 2003; Echavarria, 2014; Hilson and Osei, 2014; Hilson and Maconachie, 2017) have extensively argued the need for formalizing artisanal and small-scale mining activities. However, this has not gained much support in most African countries (including South Africa). The fascination of governments with promoting large-scale mining was cited by Hilson et al. (2020), responsible for the muting of formalizing ASM and including it in their development strategies. It should be noted and appreciated that the process of formalizing artisanal and small-scale mining activities is difficult. It is a continuous process that requires continuous support from the government. It involves the allocation of land, facilitation of miners' organization, licensing and organization of the supply chain, facilitation of access to finance and market, and monitoring and enforcement of regulations (de Haan, 2018).

The immediate solution to ASM in the Giyani and Musina areas should be to ensure that these activities are conducted with little or no environmental problems and health and safety risks. Therefore, in informal aggregate stone crushers, the health risks of noise and dust must be reduced or eliminated through the use of personal protective equipment such as dust masks and earplugs or muffs. Moreover, dust can be controlled by inclosing and/or spraying water in their sources around the plant. The use of personal protective equipment is also recommended for informal small-scale mining of mine tailings. However, the problems of dust and noise in informal mining of mine tailings are generally low. This is because the mining of mine wastes is conducted occasionally, depending on the demand for the material in the nearby communities.

In artisanal gold mining (AGM), the risk of death due to the intended invasion of the mine shafts by artisanal miners and falling into the shafts by accident is reduced by closing all disused shafts in the abandoned mine site. Strategies that provide long-term or permanent closure of the shafts should be used. These strategies may include but not limited to blast closure, backfilling of the shafts, use of concrete plugs (anchored or self-supporting), injection, and use of geo-synthetics (Mhlongo et al., 2018a; Lecomte and Niharra, 2013). These shafts sealing strategies will make it difficult for the miners to reopen the shafts during their attempt to conduct mining underground. This is because artisanal miners in the area of Giyani have always destroyed and removed structures such as concrete slabs, steel grates, and screen used to close the disused shafts (Mhlongo et al., 2019a; Mhlongo et al. 2018a). The reopening of the shafts by artisanal miners exposes the miners to the risks of abandoned mine shafts. It also reverses the efforts made to close these shafts to address the public safety hazards (Mhlongo et al., 2019a).

The miners should be advised to avoid conducting sluicing operations along the rivers. Alternatively, they should be encouraged to carryout sluicing on cemented floors found in almost all parts of the abandoned mine landscapes. In this case, the small amount of water required for sluicing can be pumped from the river and stored in redundant water reservoirs and other structures like old swimming pools found in the areas of dilapidated mine houses (see Figure 9a and b). In this case, tailings from the sluicing can backfill the shallow excavations created by the mining process. This approach to artisanal gold mining in abandoned mines landscapes is expected to significantly reduce the environmental and health risks caused by conducting sluicing along the river. The waste from in-pit sieving of gold-bearing soil can be further processed or sorted and used as aggregate in construction projects in the nearby communities. An illustration of the proposed approach for reducing the environmental problems of artisanal mining activities in Giyani is shown in Figure 10.

Figure 9. Illustration of (a) water reservoir and (b) old swimming pool that can be used to store water for sluicing around the abandoned mine sites.

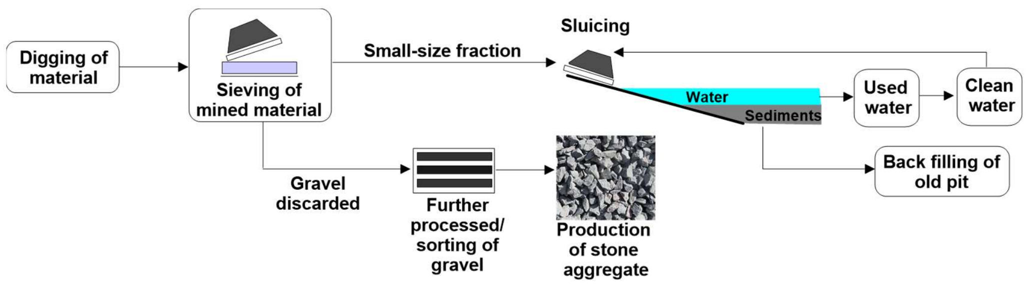

Figure 10. Flow of activities for sustainable artisanal gold mining activities in abandoned mine sites.

Conclusion

This paper analyzed the practices and problems of ASM in abandoned mines of Giyani and Musina areas. The discussion of the results revealed the need for intensifying the efforts of coming up with strategies of formalizing the management of artisanal gold mining in abandoned mines around the study area and country at large.

The prevalent of environmental risks and health and safety risks in artisanal gold mining made them not an appropriate post-mining land uses in abandoned mine sites. A formalized management of artisanal gold mining activities will go a long way in reducing their risks thus, making them sustainable post-mining land uses for abandoned mines.

Registered and informal small-scale mining activities that exploited waste rock dumps and tailings to produce stone aggregate and use in construction projects proved to be the best post-mining land-uses. These activities help to convert mine waste into new material. They also reduce the volume and environmental problems of the mine waste dump in abandoned mines.

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