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Appraisal of Strategies for Dealing with the Physical Hazards of Abandoned Surface Mine Excavations: A Case Study of Frankie and Nyala Mines in South Africa

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Abstract: In order to improve the safety status and the quality of the landscape affected by surface mining, it is important that practical strategies for dealing with the excavations are identified. The aim of the work presented in this paper was to carry out an appraisal of the strategies for addressing the physical hazards of abandoned surface mine excavations in two mines in the Limpopo Province, South Africa. The method used involved carrying out field characterization of the current state and uses of the excavations, as well as their physical hazards of the surface mine excavations in the study area. The characterization took into consideration. Possible strategies for addressing the physical hazards of the excavations are identified, and their strengths, weaknesses, opportunities, and threats (SWOT) analyzed. The Quantitative Strategic Planning Matrix (QSPM) was performed on each of the identified strategies with the purpose of determining their attractiveness based on their SWOT factors. The results of the study showed that using a combination of strategies to deal with the physical hazards of the abandoned mine excavations was the most attractive approach followed by the grading of the slopes of the excavations to improve their stability, while promoting their safe alternative uses. The no-action option and backfilling of the excavations were the least attractive strategies for dealing with the abandoned surface mine excavations. The study demonstrated how semi-quantitative tools, such as the SWOT analysis and QSPM could assist in finding practical approaches for dealing with the problems of abandoned mine sites or features.

Keywords: abandoned mines; physical hazards; surface excavation; SWOT; QSPM

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1. Introduction

Surface mining is generally known for the adverse impacts it has on the environment. Such impacts include the alteration of the landscape, deforestation and biodiversity degradation, and pollution of surface and groundwater resources [1,2]. In general, the environmental impacts of surface mining depend largely on the type of mining method used and the scale of the operation [3]. In general, the problems of mining activities (i.e., environmental problems, physical hazards and socio-economic concerns) worsen when the mine is abandoned without conducting a proper closure plan and its subsequent land rehabilitation process. Figure 1 shows the general trends of the seriousness of the problems (including physical and environmental hazards) of the mining operations throughout the different stages in the life of a mine. It demonstrates that for the majority of the cases the environmental problems, physical hazards, as well as the negative socio-economic aspects of mining get worsened when the mine is abandoned without carrying out the rehabilitation of the land affected by mining. It also shows that in some situations the impacts of these mines may remain constant (where they do not increase and/or decrease with time), while in other cases the impacts remain constant and certainly decrease over time.

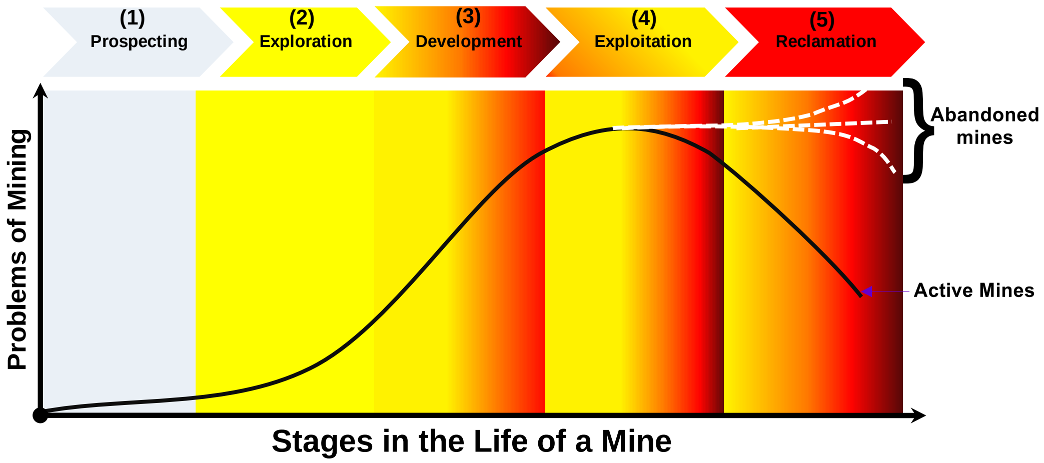

Figure 1. An illustration of the trends of the problems of mining through the stages of the life of a mine.

According to Kodir et al. [4] and Favas et al. [5], the impact of mining activities on the environment can be reduced or eliminated through the processes of reclamation, restoration and/or rehabilitation. The concept of "reclamation" of the mine includes the processes of replacement of soil materials and vegetation, often to approximate original characteristics of the mined areas and/or adjacent areas affected by mining [6]. According to Favas et al. [5], "reclamation" is basically a broad concept that encompasses terms, such as restoration, rehabilitation, placement, remediation and mitigation. In this case, "restoration" refers to the process of restoring the mine site to the previously existed condition, while "rehabilitation" comprises the design and construction of landforms or alternative vegetation depending on the desired post-mining land uses [7,8]. This paper presents the evaluation of rehabilitation strategies conducted to find appropriate strategies for dealing with the physical hazards of the areas affected by surface mining of gold and magnesite at Frankie and Nyala mines respectively. It is worth mentioning that the study focused on physical hazards because they are generally the main aspect that must be considered in closure and rehabilitation plans for open pit mine sites.

South Africa has 5650 documented abandoned mines which their rehabilitation is anticipated to cost the government about R30 Billion [9–11]. According to van Druten and Bekker [12], the rehabilitation of these mines is estimated to last for 800 years. The distribution of these mines throughout South Africa is shown in Figure 2. The focus of the rehabilitation of abandoned mines in the country have for many years been on dealing with the 1730 mines that are possessing with high risks of public safety, health and environment hazards [9]. According to Cornelissen et al. [11], to date, the government of South Africa have spent around ZAR800 million towards the rehabilitation of only 40 of the totals of 249 documented high-risk asbestos mines in the country [11]. The work reported on this paper used the case study of the situation of abandoned mine excavations found at Nyala and Frankie mines to identify the most appropriate solutions or approaches for dealing with the physical hazards presented by these excavations.

The Description of the Study Area

The Nyala and Frankie mines are respectively abandoned magnesite and gold mines found in the north-eastern part of the Limpopo Province of South Africa. The Nyala Mine is found in the village of Zwigodini, while Frankie Mine is found in the vicinity of Ka-Mapuva Village. The Frankie Mine is about 20 km outside the Giyani Town at less than 1 km distance from the banks of the Klein Letaba River. Its landscape is characterized by features, such as deep surface excavations, large heaps of spoil dumps, closed mine shafts and few dilapidated buildings [13]. On the other hand, the Nyala Mine is located on a relatively flat topography that is characterized by a few trees and shrubs. The mine landscape is characterized by five extensive surface excavations, two tailing dumps and numerous spoil dumps [14]. The general view of the landscape of both Nyala and Frankie Mines is shown in Figure 3a,b, respectively.

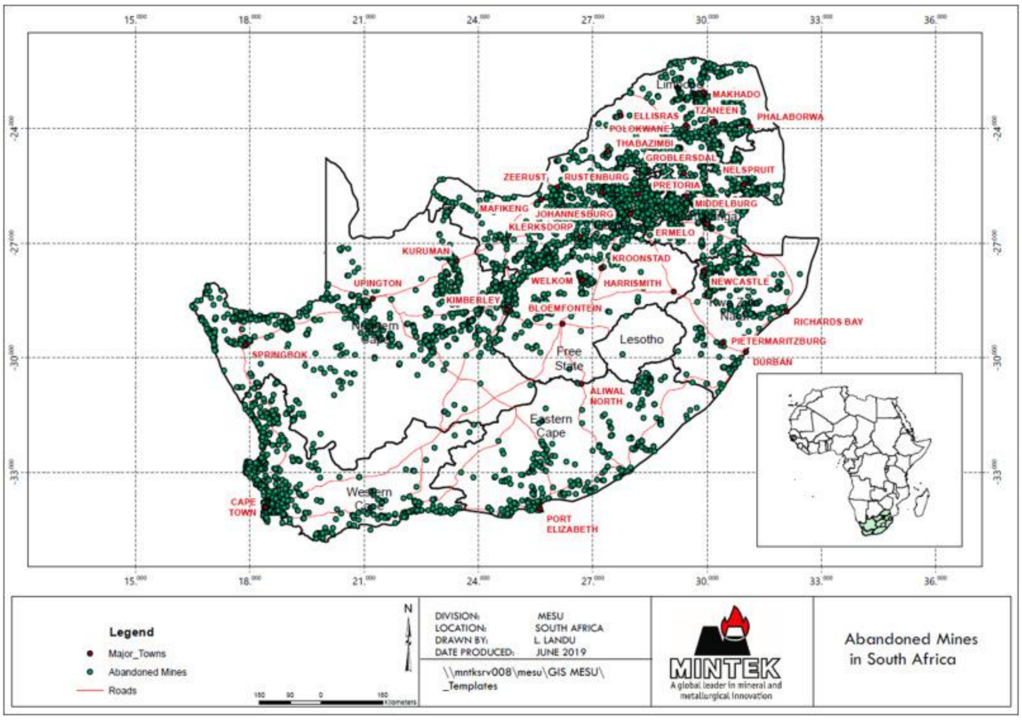

Figure 2. The distribution of the documented abandoned mines in South Africa (from Reference [11]).

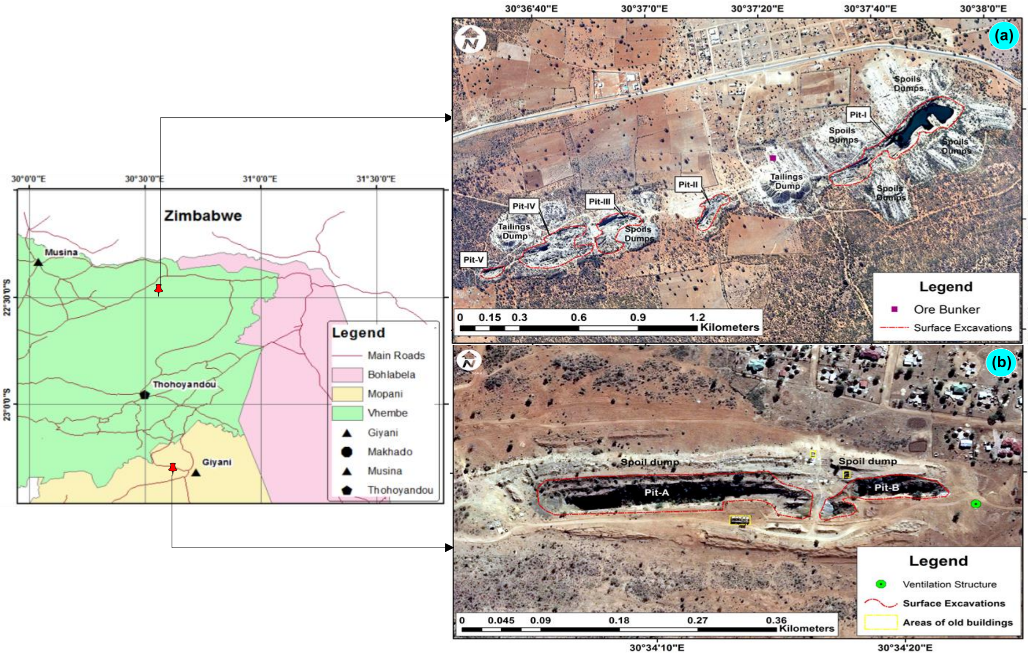

Figure 3. The distribution and the appearance of the abandoned mine landscape. (**a**) is the Nyala Mine landscape and (**b**) is the Frankie Mine landscape.

2. Methodology

The semi-quantitative methods were used to identify possible alternative options for dealing with the problems of abandoned surface mine excavations. These methods were SWOT (Strength, Weaknesses, Opportunities, and Threats) analysis and the Quantitative Strategic Planning Matrix (QSPM). The SWOT analysis is generally based on qualitative analysis without any means of analytically quantitating the intensity of the SWOT factors [15]. Consequently, where the determination of the importance of the SWOT factors is necessary, this technique has always been used by different researchers with the relevant Multi-Criteria Decision-Making methods (MCDM). The MCDM that have been used to support SWOT analysis includes the Analytical Network Process (ANP), the Analytic Hierarchy Process (AHP) and the TOPSIS [16–18].

The work of trying to find the most appropriate strategies for addressing the physical hazards of abandoned surface mine excavations, presented in this paper, started with the field characterization of the excavations. The characterization involved carrying out a detailed field description of the excavations. The purpose of doing this was to find a base for the identification of possible strategies or an alternative for dealing with the physical hazards of the abandoned surface mine excavations. It involved documentation of the current state of the excavations, their current uses, as well as the physical hazards that they possess. According to McHaina [19], the current land-uses around the mine, the viability of using the site or features and the extent of the environmental and physical hazards of the mine sites are very important in the identification of the end-uses of the mine sites. For each identified option of dealing with the physical hazards of the abandoned surface mine excavations, the SWOT analysis was performed (see Figure 4a). The results of this analysis assisted with the identification of the important issues to establish the strategies for addressing the physical hazards of the surface mine excavations. The SWOT factors of the strategies identified for evaluation in this work are presented in Table A1. It is important to note that in any project, this activity constitutes an important stage of the strategic planning process [18,20].

The identified SWOT factors of the rehabilitation strategies of the land affected by surface mining were evaluated using the technique known as the Quantitative Strategic Planning Matrix. This process included assigning weights that ranges from 0.00 to 1.00 to individual SWOT factors. This is done as a way of measuring the significance of each factor is supporting or opposing the use of the strategy being evaluated. This was conducted in a manner that demonstrates the significance of each factor over the other. In this process, the weight of 0 was used where the factor was found to be not relevant, while 1 indicated that the factor was very important. The step that followed was the rating of the SWOT factors of each strategy being evaluated by respectively assigning the attractiveness scores (AS) described in Table 1. The weight and attractiveness score of individual factors were then multiplied to obtain the value known as the total attractiveness score (TAS) of the given factors. The details of the results generated in this study using this process are presented in Tables A2 and A3. The total attractiveness scores of the strategy were then summed-up to get the total sum attractiveness score which is generally the value representing the relative attractiveness of the strategy for addressing the physical hazards of the abandoned surface mine excavations. The flowchart of this procedure, shown in Figure 4b.

Table 1. The criteria for scoring the attractiveness of the SWOT (strengths, weaknesses, opportunities, and threats) factors [21].

Attractiveness Score	Description of the Score
1	Not attractive or with major weaknesses
2	Somewhat attractive or with minor weaknesses
3	Reasonably attractive or with minor strength
4	Highly attractive or with major strength

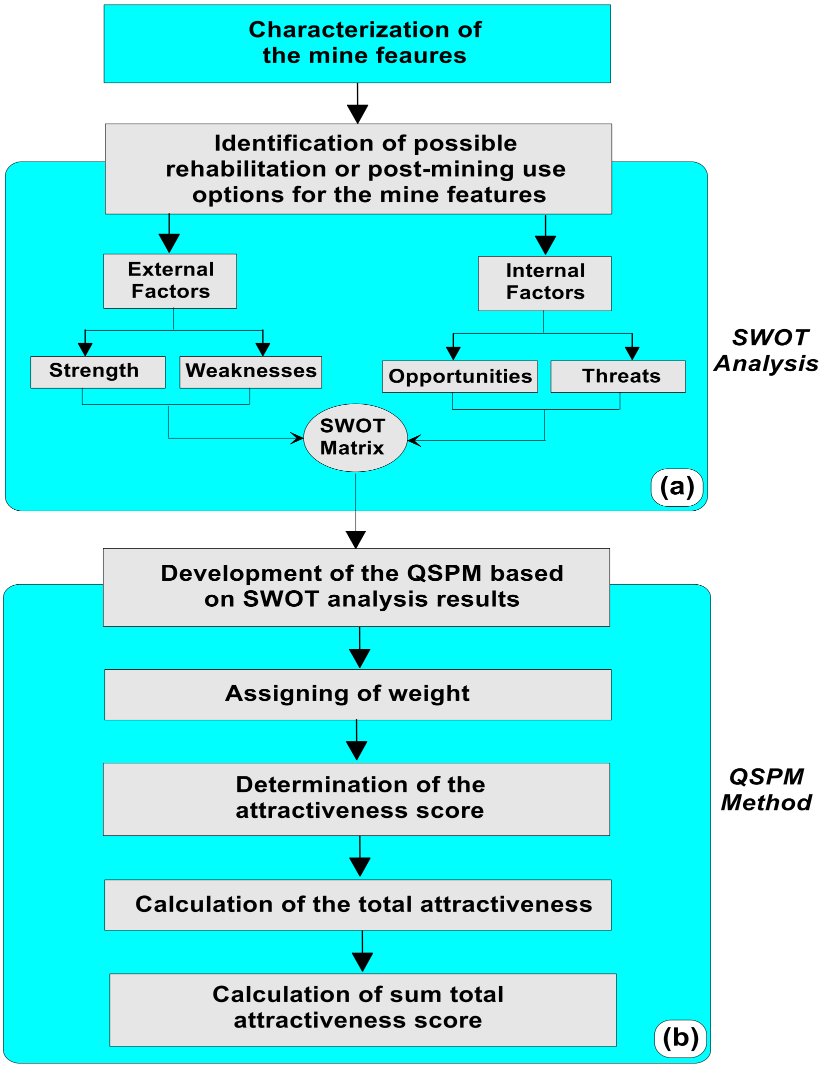

Figure 4. The flow of the methodology used to find suitable strategies for dealing with the problems of abandoned surface mine excavations. (**a**) is the SWOT analysis factors and (**b**) the Quantitative Strategic Planning Matrix (QSPM) method.

3. Results

3.1. The Issues of Abandoned Surface Mine Excavations in the Study Area

In abandoned mine sites, features, such as the surface mine excavations (open pits) are common. These excavations generally occupy a large portion of land and present a varying degree of physical hazards associated with the slopes of the excavations, the stability of the highwalls, as well as the visibility of the highwalls to the public. At Nyala Mine, the abandoned surface excavations were five, while at Frankie Mine were only two. The general characteristics of these excavations are described in Table 2. Some of the excavations were observed to be only getting filled with water during rainy days or seasons, while others contained water throughout the year.

The deepest excavation at Nyala Mine was Pit-I (~44 m maximum depth) and at Frankie Mine was Pit-A which was also characterized by the highwalls that are about 30 m high. The fact that these excavations also contained water throughout the year made them possess some secondary type of physical hazards or public health and safety risks which include drowning, consumption and getting into contact with the potentially contaminated water they contain.

Table 2. The general physical characteristics of the abandoned surface excavations.

Mine Site	Pit ID	Ava. Highwall Height (m)	Ava. Highwall Angle (°)	Total Highwall Length (m)	Area of the Pit (m^2)	Frequency of Flooding
Nyala	Pit-I	13–44	20–87	440.1	90,476.5	●
	Pit-II	15–20	83–>90	200.4	16,933.8	◐
	Pit-III	04–23	74–>90	314.6	30,010.1	◐
	Pit-IV	16–18	65–86	126.8	51,818.5	◐
	Pit-V	08–13	78–86	116.8	5824.4	◐
Frankie	Pit-A	20–30	70–90	487.8	14,199.6	•
	Pit-B	05–15	60–90	172.4	4191.0	◐

Note: ◐ indicates that the pit gets flooded only during rainy days or seasons; ● indicates that the pits are flooded throughout the year.

For example, the water in Pit-I of Nyala Mine was reported by Mhlongo and Amponsah-Dacosta [21] to be used by domestic animals as drinking water and the public as water for washing clothes, swimming and domestic fishing activities [22]. On the other hand, the water in Pit-A of Frankie Mine is currently not used by the community. However, there are high chances that domestic animals that graze around the mine site may be tempted to drink the water in the Pit-A. In addition, the domestic animals that go to the abandoned excavations at Nyala Mine for drinking water in these excavations do get killed by being trapped in sticky mud found at the floor of the excavations (see Figure 5a). In view of this, the mud formed by fine sediments deposited at the pit floor at the abandoned magnesite Nyala Mine was identified as a serious safety risk to the animals that drink the water in these excavations. Although in the case of Frankie Mine there is no death of animals reported at Frankie Mine, falling into the water that is at the bottom of Pit-A can result to death with no possibilities of successful recovery of the body. This is because the bottom part of this excavation is connected to the underground open stope, which is filled up with groundwater (see Figure 5b).

The other obvious risk of abandoned surface mine excavations is falling of people and animals from deep highwalls that have a potential of resulting in serious bodily injury or death. The body injuries can also be due to the highwalls falling on victims who might be within the pit during the incident. The fact that some of the highwalls were in locations where they cannot be easily seen by the members of the public and that were also in proximity to access routes were the factors identified to can lead to people an animal accidentally falling from the highwalls of some of the excavations (especially at Frankie Mine). The approximate location and the view of the highwalls section of the excavation from the access route at Frankie Mine are shown in Figure 6a. These issues were also the concerns identified in most excavations of Nyala Mine. The reason for this is the fact that in both mines the surface mine excavations were found open to the public in the way that allows domestic animals from the nearby communities that graze around these mine sites to easily access the excavations.

Figure 5. (**a**) The evidence of the animals killed by being trapped in mud at the pit floor [10], and (**b**) is an illustration of the connection of the surface excavation with the underground open stope filled with water.

Figure 6. (**a**) An illustration of the close location of the excavation to the access route and Frankie Mine, and (**b**) the unstable highwalls of the excavations at Nyala Mine.

In addition, the risks of falling from the highwalls or being injured, due to the falling of the rocks from the highwalls were identified to be the common problems associated with the abandoned surface excavations in both mines in the study area. This is because all the excavations were found with sections of the highwalls that are about 5 m high and even more. This alone contributes to such highwalls being unstable. The other factor contributing to the highwalls of the excavations in the study area is prone to collapse the fact that they are mostly characterized by deteriorating rock-mass which generally make it easy for rock falls to occur [23]. Some of these highwalls were found with slopes that were greater than 90° (see Figure 6b), while others had fissures developed, which are evidence ground movement towards the excavations [13]. The major concerns of this situation are that both people and animals may be tempted to work above these highwalls or take refuge in the shadows provided by the highwalls, thus, exposing themselves to the safety risks of such excavations. It is important to note that, generally in operational mines; it is recommended that no persons can be at a distance of less than 25% of the highwall height [24]. However, with the situation of unrestricted public access to abandoned surface mine excavations, it is impossible to control the public exposure to the physical hazards of the highwalls of the abandoned surface mine excavations.

3.2. Possibility of the Backfilling of the Excavations at and the Cost Implications

The use of a surface mining method to mine magnesite at Nyala Mine resulted in the landscape characterized by several shallow and deep excavations, as well as the heaps of spoils and tailings material. This has resulted in a considerable large (169 ha) area being unusable and having reduced aesthetic beauty. Based on this, the rehabilitation of the Nyala Mine terrain is expected to involve carryout some earthworks which involve grading of the mine terrain to fill the void areas (i.e., cut-and-fill operations), spreading of fill material, and ripping of footprint areas to prepare the soil for the natural growth of vegetation. The areas of cut-and-fill in different parts of the Nyala Mine terrain are shown in Figure 7. Collectively, the operations of rehabilitation of the Nyala Mine land (excluding the backfilling of Pit-I) is likely to cost between ZAR 4.7 million and ZAR 5.8 million. They are expected to involve cutting of about 2,269,277 m^3 of material to fill a void of about 2,095,037 m^3, spreading of fill material over an area of approximately 716,409 m^2 (72 ha), and ripping of footprint areas of about 971,917 m^2 (97 ha) [25].

On the other hand, the Frankie Mine was found characterized relatively small spoils dump; thus, there is very little backfilling of the excavations that can be conducted in this abandoned mine site. The dump of spoil material found at Frankie Mine is generally of stable slopes which are completely covered with native grasses. These have resulted in the spoil dumps at Frankie Mine having a relatively low impact on the aesthetic appearance of the mine landscape. Figure 8 shows the appearance of the spoil dumps of Frankie Mine from the nearby community and access route.

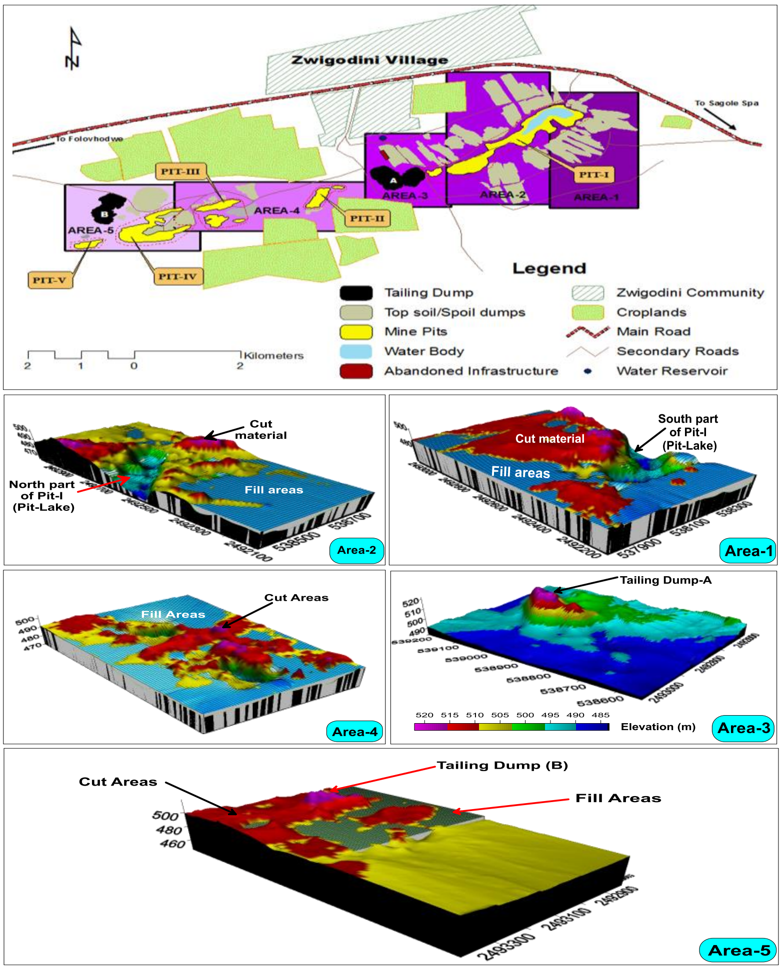

Figure 7. An illustration of cut and fill areas at Nyala Mine [25].

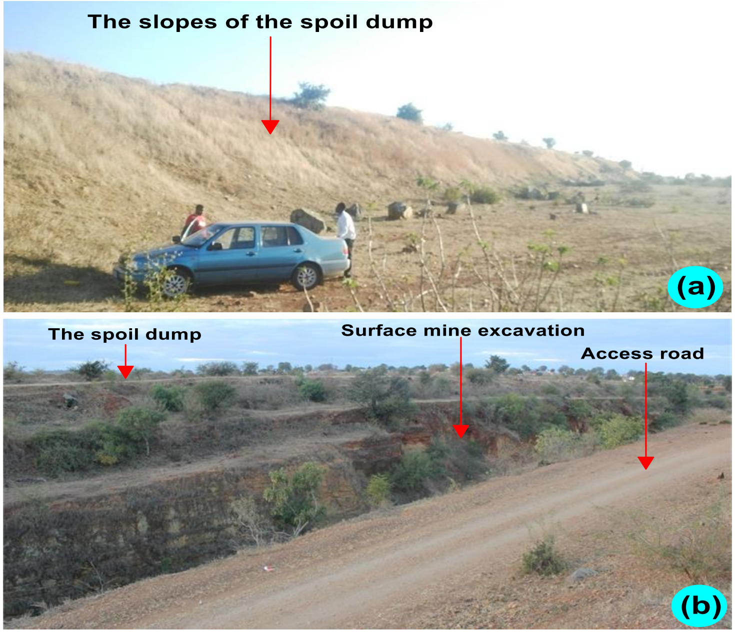

Figure 8. (**a**) The community facing slopes of the spoil dumps and (**b**) the access route and pit facing slopes of the spoil dumps at Frankie Mine.

3.3. Approaches for Rehabilitation of Abandoned Surface Excavations

The evaluation of about five strategies or approaches for dealing with the physical hazards of abandoned surface excavations was conducted using the QSPM method. These approaches were no-action option, backfilling of the excavations, fencing of the excavations to restrict access, reshaping of the highwalls and stabilization of the slopes of the excavations to promote their alternative uses, and the option of combining reshaping of highwalls with fencing to enhance the safety status of the excavations, while ensuring that they are at a stage where they can support different post-mining uses. The evaluation of the abandoned surface excavation rehabilitation approaches was conducted based on their identified SWOT factors presented in Table A1.

The results of the analysis of the attractiveness of the strategies for addressing the physical hazards of the excavations (both, those that contained water and those that were without water) demonstrated that using a combination of approaches in dealing with the physical hazards of these excavations was the most attractive approach. This is because the use of this approach had the potential of addressing the physical hazards of the abandoned excavations in the manner that promote the reuse of the excavations, while improving the aesthetic appearance of the landscape. Moreover, the reuse of the excavations promises to reduce the high costs that are associated with the extensive earthworks of backfilling the disused surface mine excavations. However, the second most attractive strategy for water containing excavations was the reshaping of the highwalls and stabilization of the slopes of the excavations to promote the safety uses of the water in the abandoned surface mine excavations. In the case of dry excavations, the restriction of access of the abandoned surface excavations through the erection of a fence around the excavations was found to be the second most attractive rehabilitation approach (see Figure 9).

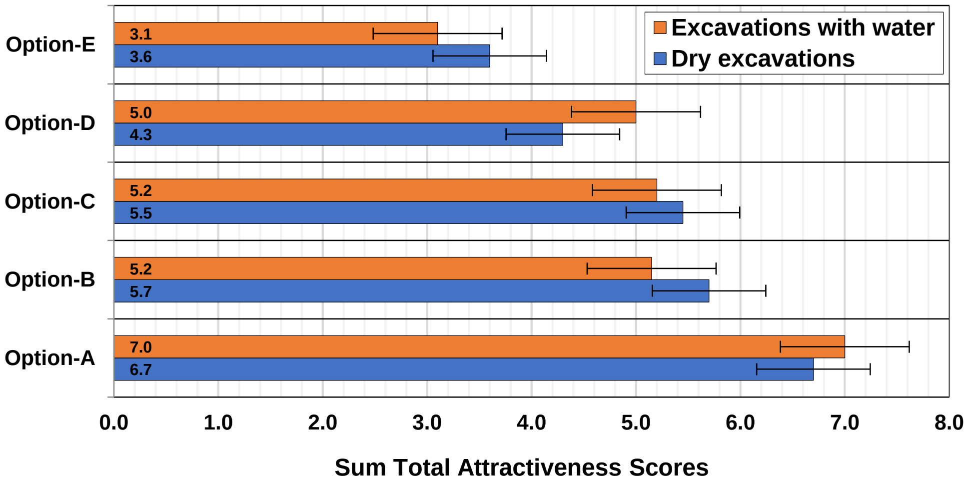

Figure 9. Comparison of the attractiveness of the rehabilitation options in addressing the issues of abandoned surface excavations. **A** is the combination of strategies, **B** is the reduction of highwalls and reuse of the excavations, **C** is the fencing of the excavations, **D** is the backfilling of the excavations, and **E** is a no-action option.

The differences in the position of these rehabilitation strategies in the priority of options for dealing with the physical hazards of water containing and dry excavations were somehow influenced by the fact that the identification of post-mining uses for dry excavations is mostly not that easy. On the other hand, it is generally relatively easy to identify potential uses for flooded mine excavations. In view of this, it is important that the fencing of dry excavations is implemented as a temporary strategy for protection of people and animals from the hazards they present, while efforts of finding the most appropriate uses of the excavations are underway.

In both situations, the least attractive approach of addressing the problems of abandoned surface mine excavations was the no-action option. This is mainly because this approach tern to maintain the current unsafe use and conditions of the excavations. The second least attractive approach was backfilling of the excavations using different materials, including mine spoils and tailings. Some of the materials that are available around the abandoned mine sites and can be used to backfill unused surface mine excavations with the aim of ensuring the morphological recovery of the landscape affected by surface mining are tailings, waste rocks, spoils, and overburden material [5]. Although this approach appears to be the ideal option for abandoned mines situation, it generally has several disadvantages than other strategies. These include the fact that (i) there might be no enough material near the site and (ii) the high earthwork requirements that are generally costly to conduct. Moreover, backfilling turn to eliminate the opportunities of future beneficial uses of the surface mine excavations. The comparison of the total attractiveness score of the approaches for dealing with the physical hazards of the abandoned surface mine excavations at Nyala and Frankie mines is shown in Figure 9. The detailed results of the attractiveness scores of the approaches for dealing with the physical hazards of the abandoned mine excavations as generated in this study using the QSPM technique are shown in Tables A2 and A3.

4. Discussion

The major concerns of the surface mine excavations are safety, health hazards, and the visual appearance of the landscape [26–28]. According to Tsolaki-Fiak et al. [29] and Misthos et al. [30], the appearance of surface excavation and/or quarrying sites with contrasting colours on the landscape turns to reduce the aesthetic appeal of the landscape, thus, resulting to the deterioration of the scenic quality of the area.

This work found that surface mine excavations mostly occupy a large area of the abandoned mine landscape. Depending on the location of such excavations, they can be a serious hindrance to urban development [31]. Also, safety and health risks are associated with their highwalls and deep waters that fill up some of the excavations. Backfilling of surface excavations with material, such as waste rock, tailings, soil and spoil materials is often considered. According to Favas et al. [5] and Johnson and Carroll [32], backfilling can be implemented as complete or partial backfilling and can be followed by the establishment of vegetation on the backfilled areas.

Although the backfilling of excavations for morphological restoration have several advantages, the attractiveness of this method in dealing with the physical hazards and some of the environmental problems of the sites that are affected by surface mining is mainly affected by the potentially high costs of the backfilling operations and the lack of locally available material for backfilling the abandoned excavations. As a result, the less costly strategies that are implemented to protect the public from the physical hazards of the excavations, while promoting the safe and easy reuses of the excavations for other purposes was found to be more attractive than the option of backfilling the excavations. For example, in different countries (e.g., Germany, Poland, Czech Republic), old surface mine excavations have been developed to pit-lakes (or lake districts) that supports a variety of activities, which includes, but not limited to, aquaculture, aquatic sports, shipping and recreational activities [29,31]. The development of Pit-I of Nyala Mine to a pit-lake through the reduction of the slope angle of its walls (including highwalls), controlling of the level of sediment deposition at the pit floor, and the improvement of the quality of the water in the pit was proposed and argued by Mhlongo and Amponsah-Dacosta [14]. The abandoned surface mine excavation can also be developed for use as a waste disposal facility or landfill sites [25,33]. In general, all these reuses of abandoned surface mine excavations require that the slopes of the excavations are graded to maintain a safer and stable angle. The restriction of access through the fencing of the excavations may also be necessary. An illustration of Pit-I filled with water after the rainy days at Nyala Mine is shown in Figure 10.

Three approaches for addressing the physical hazards of abandoned surface mine excavations are listed in Figure 11. The first approach was backfilling of the excavations to make the land occupied by the excavations available for other uses. The area of backfilled excavations can be used for crop farming, site for animal grazing, forest and wildlife conservation development, and development of settlement and/or industrial site. The other approaches of addressing the physical hazards of the surface mine excavations can be erecting a fence around the excavations and reshaping of the walls of the excavations to make them safe and stable. This can ensure that the beneficial reuses of the abandoned mine excavations are safety implemented. Some of the possible reuses of the old surface mine excavations are included in Figure 11.

Figure 10. The water-filled excavation (Pit-I) of the abandoned Nyala Mine.

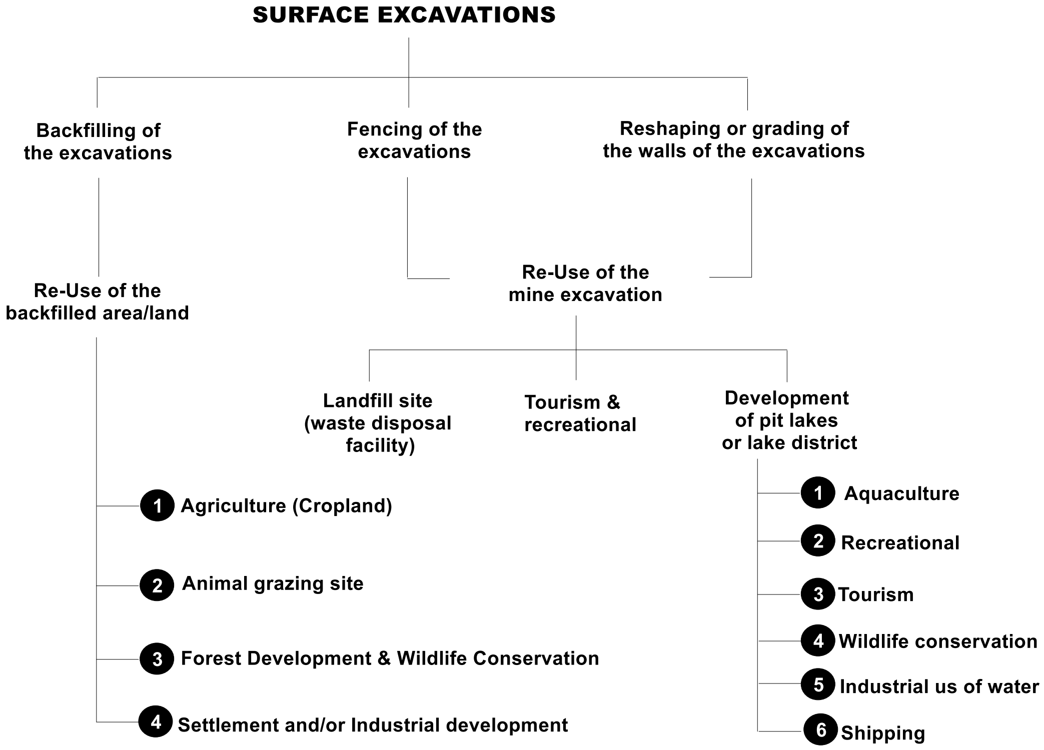

Figure 11. The summary of the practical approaches for addressing the problems of abandoned surface mine excavations.

5. Conclusions

The field characterization of the abandoned surface mine excavations identified the physical hazards of these excavations to be associated with their highwalls, highwall's stability and the sticky mud that trap and cause death to animals that drink the water in the abandoned excavations at Nyala Mine. The SWOT and QSPM analysis of the possible and practical approaches for dealing with the physical hazards of abandoned surface mine excavations assisted in finding possible alternative uses of the excavations besides backfilling. The adoptive re-use of the abandoned mine excavations promises to contribute positively to the socio-economic development of the communities around the abandoned mine sites. This is because the new uses of the excavations are likely to create new economic opportunities that can replace those lost due to the closure or abandonment of the mining operations. A formal characterization of the physical hazards of abandoned surface mine can be of assistance in the management of abandoned surface mine excavations elsewhere. Although the semi-quantitative methods used in this study assisted in pointing out the possible alternative strategies for dealing with the physical hazards of the abandoned surface mine excavations, it is recommended that the results of these tools be considered fit for only the pre-feasibility study part of the rehabilitation work. More quantitative tools should be used for decision-making studies.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The results of SWOT analysis of the strategies or approaches of dealing with the problems of abandoned surface mine excavations.

Mine Feature	SWOT Parameters	Strength	Weaknesses	Opportunities	Threats
Excavations with water throughout all reasons	Backfilling	Elimination of all risks of the pits and the water Creation of flat topography	Intense earthworks required Require large volumes of soil	Large land can be made available other land-uses	The backfill material might not be always enough The cost of earthworks is mostly high. Opportunities for beneficial use of the pit will completely be eliminated
	Fencing	Exposure to hazards of the pit will be eliminated The installation of the fence is mostly less costly	Not all land occupied by the pits can be used for other uses	The current use of the water in the pit can will be still possible.	Constant maintenance of the fence will be required. Does not remove the risks associated with the pits The current informal uses of the pit will be eliminated
	Reduction of highwalls and reuse of the pit	Eliminates the risks of falling from the highwalls. Reduced earthworks requirement Relatively low cost of rehabilitation Relatively less maintenance of rehabilitation work required	Does not address the risks of drowning and being trapped in mud at the pit floor.	Other commercial uses of the pit can be explored. The pit can be developed to a complete pit lake.	The approach can be easily supported by the host community
	No action	No or very little earthwork requirement Extremely reduced cost of rehabilitation There can be little, or no maintenance required	The risks of highwalls might be not addressed The risks of using water in the pit might remain Promotion of the beneficial use of the pit and its waters	Other uses of the pit and land can be later explored	The approach will not address the current risks of the pit.
	Use of combined strategies (reduction of highwall, fencing and reuse of the pit)	The majority of the risks of the pits will be addressed. The aesthetic appearance of the mine landscape can be improved	Relatively high cost of rehabilitation and maintenance	New opportunities of the use of the pit can be identified. The current land can be transported to support the nearby community	Longer and costly maintenance of the site might be required
Seasonally flooded excavations	Backfilling	Elimination of all risks of the pits and the water Creation of flat topography	Intense earthworks required Require large volumes of soil	Large land can be made available other land-uses	The backfill material might not be always enough. The cost of earthworks is mostly high. Opportunities for beneficial use of the pit will completely be eliminated
	Fencing	Exposure to hazards of the pit will be eliminated. The installation of the fence is mostly less costly	Not all land occupied by the pits can be used for other uses	Future use of the pit can be conceptualized	Constant maintenance of the fence will be required. Does not remove the risks associated with the pits The current informal uses of the pit will be eliminated
	Reduction of highwalls and reusing the pit	Eliminates the risks of falling from the highwalls. Reduced earthworks requirement Relatively low cost of rehabilitation Relatively less maintenance of rehabilitation work required	Does not address the risks of drowning and being trapped in mud at the pit floor during rainy days.	Other beneficial uses of the pit can be later identified and implemented.	The approach can be easily supported by the host community
	No action	No or very little earthwork requirement Extremely reduced cost of rehabilitation There can be little, or no maintenance required	The risks of highwalls might be not addressed The risks of using water in the pit might remain	Other uses of the pit and land can be later explored	The approach will not address the current risks of the pit.
	Use of combined strategies (reduction of highwall, fencing and reuse of the pit)	The majority of the risks of the pits will be addressed. The aesthetic appearance of the mine landscape can be improved	Relatively high cost of rehabilitation and maintenance	New opportunities of the use of the pit can be identified. The current land can be transported to support the nearby community	Longer and costly maintenance of the site might be required

Table A2. The results of QSPM analysis of the rehabilitation strategies for flooded excavations.

Backfilling			
	Weight	**Attractiveness Score**	**Total Attractiveness Score**
Strength			
Elimination of all risks of the pits and the water	0.30	4.00	1.20
Creation of flat topography	0.25	3.00	0.75
Weaknesses			
Intense earthworks required	0.25	1.00	0.25
Require large volumes of soil	0.20	1.00	0.20
Sum weight	1.00		2.40
Opportunities			
Large land can be made available other land-uses	0.30	4.00	1.2
Threats			
The backfill material might not be always enough	0.20	1.00	0.20
The cost of earthworks is mostly high.	0.25	1.00	0.25
Opportunities for beneficial use of the pit will completely be eliminated	0.25	1.00	0.25
Sum Weight	1.00		1.90
Sum Total Attractiveness Score		**4.30**	
Fencing			
Strength			
Exposure to hazards of the pit will be reduced	0.4	4.00	1.60
The installation of the fence is mostly less costly	0.35	3.00	1.05
Weaknesses			
Not all land occupied by the pits can be used for other uses	0.25	2.00	0.50
Sum weight	1.00		3.15
Opportunities			
The current use of the water in the pit can will be still possible	0.55	3.00	1.65
Threats			
Constant maintenance of the fence will be required.	0.20	2.00	0.40
Does not remove the risks associated with the pits	0.15	1.00	0.15
The current informal uses of the pit will be eliminated	0.10	1.00	0.10
Sum Weight	1.00		2.30
Sum Total Attractiveness Score		**5.45**	
Reduction of highwalls and reuse of the pit			
Strength			
Eliminates the risks of falling from the highwalls.	0.30	4	1.20
Reduced earthworks requirement	0.30	2	0.60
Relatively low cost of rehabilitation	0.20	1	0.20
Relatively less maintenance of rehabilitation work required	0.10	1	0.10
Weaknesses			
Does not address the risks of drowning and being trapped in mud at the pit floor.	0.10	1	0.10
Sum Weight	1.00		2.20
Opportunities			
Other commercial uses of the pit can be explored.	0.40	4	1.60
The pit can be developed to a complete pit lake.	0.40	4	1.60
The approach can be easily supported by the host community	0.10	2	0.20
Threats			
New risks might manifest	0.10	1	0.1
Sum Weight	1.00		3.50
Sum Total Attractiveness Score		**5.70**	

Table A2. *Cont.*

	No Action			
Strength				
	No or very little earthwork requirement	0.20	2	0.4
	Extremely reduced cost of rehabilitation	0.20	2	0.4
	There can be little, or no maintenance required	0.30	1	0.3
Weaknesses				
	The risks of highwalls might be not addressed	0.10	1	0.1
	The risks of using water in the pit might remain	0.10	1	0.1
	Promotion of the beneficial use of the pit and its waters	0.10	1	0.1
Sum Weight		1.00		1.4
Opportunities				
	Other uses of the pit and land can be later explored	0.6	3	1.8
Threats				
	The approach will not address the current risks of the pit.	0.20	1	0.2
	The risks of the pit might escalate	0.20	1	0.2
Sum Weight		1.00		2.2
Sum Total Attractiveness Score			**3.6**	
	Use of Combined Strategies (Reduction of Highwall, Fencing and Reuse of the Pit)			
Strength				
	The majority of the risks of the pits will be addressed.	0.50	4.00	2.00
	The aesthetic appearance of the mine landscape can be improved	0.40	3.00	1.20
Weaknesses				
	Relatively high cost of rehabilitation	0.10	1.00	0.10
Sum Weight		1.00		3.30
Opportunities				
	The current land can be transported to support the nearby community	0.40	4.00	1.6
	New opportunities of the use of the pit can be identified.	0.40	4.00	1.6
Threats				
	Longer and costly maintenance of the site might be required	0.20	1.00	0.2
Sum Weight		1.00		3.4
Sum Total Attractiveness Score			**6.70**	

Table A3. The results of QSPM analysis of the rehabilitation strategies for dry excavations.

		Backfilling		
Strength				
	Elimination of all risks of the pits and the water	0.40	4.00	1.60
	Creation of flat topography	0.30	3.00	0.90
Weaknesses				
	Intense earthworks required	0.15	1.00	0.15
	Require large volumes of soil	0.15	1.00	0.15
Sum Weight		1.00		2.80
Opportunities				
	Large land can be made available other land-uses	0.40	4.00	1.6
Threats				
	The backfill material might not be always enough	0.20	1.00	0.20
	The cost of earthworks is mostly high.	0.20	1.00	0.20
	Opportunities for beneficial use of the pit will completely be eliminated	0.20	1.00	0.20
Sum Weight		1.00		2.20
Sum Total Attractiveness Score			**5.00**	
	Reduction of Highwalls and Reusing the Pit			
Strength				
	Eliminates the risks of falling from the highwalls.	0.40	4.00	1.60
	Reduced earthworks requirement	0.30	3.00	0.90
	Relatively low cost of rehabilitation	0.10	3.00	0.30
	Relatively less maintenance of rehabilitation work required	0.10	3.00	0.30
Weaknesses				
	Does not address the risks of drowning and being trapped in mud at the pit floor during rainy days.	0.10	1.00	0.10
Sum Weight		1.00		3.20
Opportunities				
	Other beneficial uses of the pit can be later identified and implemented.	0.80	2.00	1.6
Threats				
	The community will be still exposed to the hazards of the pit	0.20	2.00	0.40
Sum Weight		1.00		2.00
Sum Total Attractiveness Score			**5.20**	
	Fencing			
Strength				
	Exposure to hazards of the pit will be eliminated.	0.50	4.00	2.00
	The installation of the fence is less costly	0.30	2.00	0.60
Weaknesses				
	Not all land occupied by the pits can be used for other uses	0.20	2.00	0.40
Sum Weight		1.00		3.00
Opportunities				
	Future use of the pit can be conceptualized and implemented	0.60	3.00	1.8
Threats				
	Constant maintenance of the fence will be required.	0.15	1.00	0.15
	Does not remove the risks associated with the pits	0.15	1.00	0.15
	The current informal uses of the pit will be eliminated	0.10	1.00	0.10
Sum Weight		1.00		2.20
Sum Total Attractiveness Score			**5.20**	

Table A3. *Cont.*

No Action				
Strength				
	No or very little earthwork requirement	0.20	2.00	0.40
	Extremely reduced cost of rehabilitation	0.20	2.00	0.40
	There can be little, or no maintenance required	0.20	2.00	0.40
Weaknesses				
	The risks of highwalls might be not addressed	0.20	1.00	0.20
	The risks of using water in the pit might remain	0.20	1.00	0.20
Sum Weight		1.00		1.60
Opportunities				
	Other uses of the pit and land can be later explored	0.50	2.00	1
Threats				
	The approach will not address the current risks of the pit.	0.50	1.00	0.50
Sum Weight		1.00		1.50
Sum Total Attractiveness Score			**3.10**	
Use of Combined Strategies (Reduction of Highwall, Fencing and Reuse of the Pit)				
Strength				
	The majority of the risks of the pits will be addressed.	0.40	4.00	1.60
	The aesthetic appearance of the mine landscape can be improved	0.40	4.00	1.60
Weaknesses				
	Relatively high cost of rehabilitation and maintenance	0.20	2.00	0.40
Sum Weight		1.00		3.60
Opportunities				
	New opportunities of the use of the pit can be identified.	0.40	4.00	1.6
	The current land can be transported to support the nearby community	0.40	4.00	1.6
Threats				
	Longer and costly maintenance of the site might be required	0.20	1.00	0.20
Sum Weight		1.00		3.40
Sum Total Attractiveness Score			**7.00**	

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