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Rehabilitation of Abandoned open Excavation for Beneficial use of the pit Lake at Nyala Magnesite Mine

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ABSTRACT: Abandoned surface mine excavations can be a major environmental, social and/or human health problem for the mining industry as well as for the community living nearby. This problem is exacerbated by the rapidly growing population encroaching on areas of historic mined lands. The aim of this study was to assess the safety status of the historic Nyala Mine excavation with the purpose of coming up with rehabilitation options that promote the beneficial use of the pit lake. The study involved characterisation of the abandoned excavation through field description, modelling of both the geometry of the pit and the flow of surface runoff in to the pit, and chemical analysis of the pit lake water. A survey of the pit landscape showed pit walls of up to 22m high with a slope angle ranging from 10° to 30°. The pit was found to be accumulating runoff water from high grounds along the northern part of the excavation. Pit water was found to be alkaline (pH ±9.6), with F^- (±1.1 ppm), Cl^- (±169.6 ppm), Mg^{2+} (±67.85 ppm) and K^+ (±87.16 ppm) concentrations that were all above the standards permissible for domestic use. This study demonstrated that beside backfilling of old mines excavations; rehabilitation techniques that transform lifeless landscapes into prosperous ones, with beneficial end uses can be considered.

Key words: Mine Pit Lake, Nyala Mine, Abandoned mines, Public safety

INTRODUCTION

Mining operations are responsible for the degradation of large areas of sometimes potentially cultivable land, replacing the existing ecosystem with massive volumes of waste materials such as spoils and tailings dumps (Singh *et al.,* 2007). According to Smith (2009), the type of mining method used in the extraction of mineral resources as well as the geographical location of the mine are among the major factors that determine the extent to which mining degrades the environment. The environmental effect of mining is localised and only affects the mine lease area, but pollution as a result of the waste rock, tailings and spoil dumps that is generated can have severe impact that extends to nearby properties (Sahu and Dash, 2011; Allen *et al.,* 2001). Mining of magnesite by surface mining at Nyala Mine has affected the natural landscape to a greater extent (Mhlongo *et al.,* 2013a).

Nyala Mine is characterised by four shallow and less extensive pits. In addition to these pits, the mine has one extensive pit which contains water throughout the year. This pit was rated by Mhlongo et al. (2013b); the most hazardous mine feature to both the environment and the members of the public. According to Mhlongo et al. (2013b), the pit contains large volume of water, thick sticky mud at the pit floor, and has unstable pit walls and therefore presents a serious physical hazard. According to Deupe and Lymbery (2005), pit lakes have several alternative end-uses that include recreation and tourism, wildlife conservation, aquaculture, irrigation, livestock and industrial water sources and chemical extraction. It is also worth noting that the beneficial use of mine pit lakes depends largely on the quality of the water in the pit as well as the safety status of the abandoned excavation. Consequently, this research was conducted with the aim of assessing the safety status of the abandoned excavation at Nyala Mine so as to come up with rehabilitation options that promote the beneficial use of the pit lake.

The abandoned Nyala mine is found at the far north eastern corner of the Limpopo Province of South Africa in the small but fast growing village of Zwigodini. It is between the coordinates of 22° 45' S to 22° 33' S and 30° 36' E and 30° 39' E (see Fig 1). The mine lease area and the Zwigodini area at large are characterised by fairly flat topographic relief

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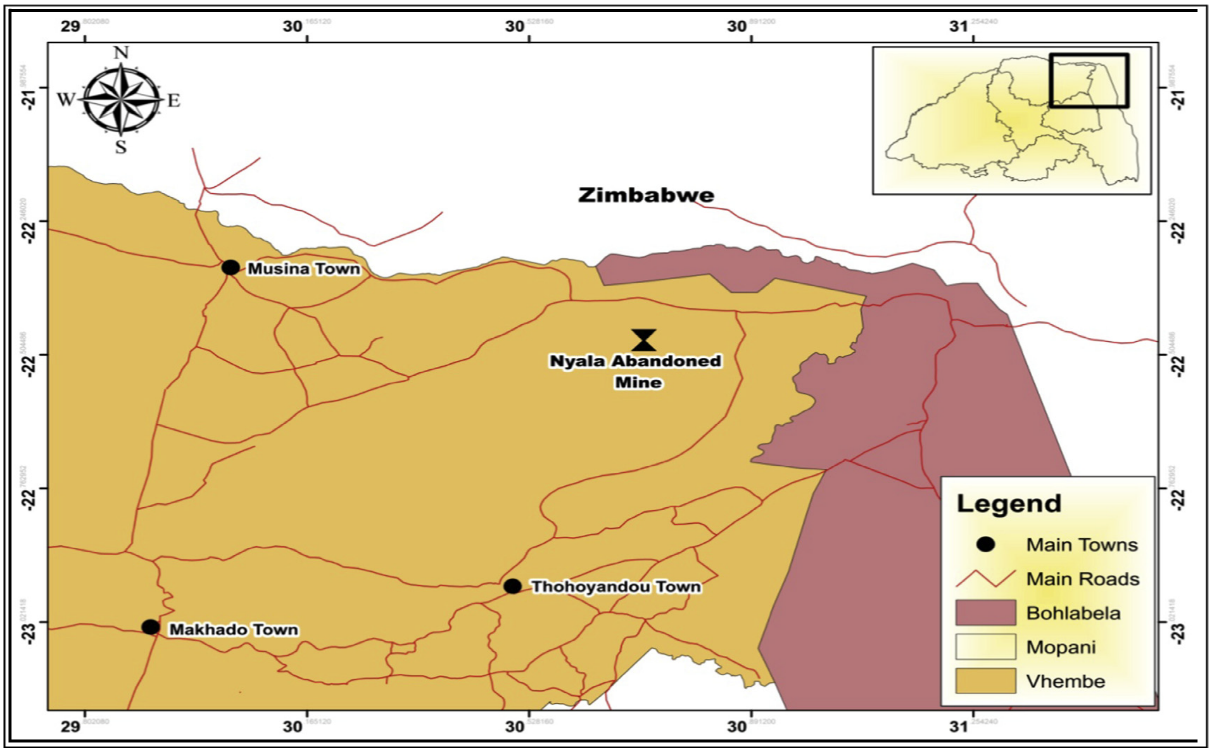

Fig.1. Geographical location of the abandoned Nyala Mine (Mhlongo et al. 2013a)

which is generally influenced by the underlying geology. There are no high grounds or hills from which the mine area can be overlooked. The landscape is covered by sparse trees, patches of grass and few shrubs.

The climate of the area is that of the far north-eastern part of the Limpopo Province. It is characterised by very hot summers with low rainfalls and mild winters. It experiences summer temperatures that go beyond 40°C and the minimum temperatures that range between 20°C and 25°C during the winter season. There are no flowing streams around and as a result the community around the mine rely on groundwater resources for domestic uses.

METHODS & MATERIALS

The initial step in the collection of the data to meet the objective of this study was the field description of the pit lake and its surrounding areas. The field description of the pit looked more precisely into the current state of the excavation or Pit Lake, the current use of the Pit Lake and analysis of major physical hazards that are associated with the abandoned open excavation.

Following the pit lake site description, the detailed characterisation of the pit and its surrounding environs from the constructed topographic map, watershed areas and terrain slopes maps was conducted. The slope angle of the pit walls was modeled with the aim of identifying the cut line in the design of the most appropriate final pit slope angle. In order to achieve these, land elevation data collected using an RTK GPS System (Hi-Target V9 GNSS RTK Surveying System) was used as an input data in the modelling of the terrain parameters. Using the GPS system; about 2644 points were recorded at every 1 to 2 metres vertical intervals along the traverse lines of 15 to 20 m intervals. The simulation of surface water flow into and around the pit was achieved by superimposition of the vector map showing the direction of water flow through the use of oriented arrows over the map of the watershed areas.

Water samples were collected from the pit lake and laboratory analysis conducted. Parameters considered were pH, electrical conductivity (EC) and both non-metallic (anions) and metallic (cations) elements concentration. The anions and cations concentration in water were analysed using an Ion Chromograph (850 professional IC) and Flame Atomic Absorption Spectrometry (Perkin Elmer AAnalyst 400), respectively. The analysed anions were F^-, Cl^-, NO_3^-, PO_4^{3-} and SO_4^{2-} while the cations were Na^+, Ca^{2+}, Mg^{2+}, K^+ and Fe^{3+}.

RESULTS & DISCUSSION

The Nyala Mine Pit Lake was found to extend laterally for more than 600 m at an average width of 113 m. Most of the walls of the pit lake were relatively flat and less hazardous when compared with the other abandoned pits in the mine area. The volume of the water in the pit varies seasonally and the water is used by animals as drinking water (see Fig.2a), and for domestic purposes such as washing of cloths and recreational purposes (i.e. swimming). In addition, fishing activities were also identified as one of the activities currently supported by the pit lake.

The existence of fish in the pit lake and the fact that animals such as cows, donkeys and goats have been drinking the water in the pit for a long time without any health problem are indications that the pit lake may have some beneficial uses. However, there have been numerous reports of cattle being trapped by mud on the pit floor of the Pit Lake and subsequent death. Part of the skeleton of an animal (cow) which died as a result of being trapped by mud in relatively dry portion of the pit lake is shown in Fig. 2b.

This abandoned open excavation extends over an area of about 105685 m^2 (≈ 10.57 ha) while attaining the maximum depth of approximately 22 m along the south western part. It gradually becomes shallower as moving towards the north eastern portion as shown in the cross section constructed along the strike of the pit (see Fig.3 (I)). The deepest part of the pit carries a large volume of water that is used by both domestic and wild animals as drinking water, while the rest of the pit only get flooded with water during rainy season. About 100 m from the pit lake, towards the north eastern part of the study area, there is a huge and extensively eroded magnesite tailing (see Fig.3 (I)). According to Sibanda et al. (2013), this tailing is made up of alkali (±8.5 pH value) materials which are of well-graded sands and comprising of about 43.32% silica.

In order to identify an appropriate final pit walls slope design, there was a need for the analysis of the current slopes of the excavation. Modelling of the slopes characterising the pit and the surrounding environments indicated that the terrain slopes in the area range from absolutely flat (0°) to slopes that are greater than 40° as shown in Fig.3(II). The pit slope angle was analysed and found to be ranging from approximately 10° and to maximum of about 30°. The dominating pit slope angle was found to be ranging from 16° to 24° with very few pit walls characterised by slopes that are greater than 24° and less than 16°. During field work few slopes were observed with angles that average approximately 87°.

Following the terrain slope analysis, modelling of watershed areas around the abandoned Nyala Mine pit lake revealed that the excavation receives most of the runoff water from the north western part of the pit lake. This means that effective and most appropriate engineering erosion control measures to limit or eliminate sedimentation in the pit floor need to be erected along this identified high runoff potential areas. The superimposition of the vector map showing the direction of rain water flow along the terrain within and around the abandoned excavation on the watershed areas gave a clear indication of the expected direction of surface runoff. The map showed that much of surface runoff water is expected to start from the north eastern part of the excavation characterised by elevated grounds covered by one of the tailings dumps in the area. The watershed area and the direction of surface water flow in the area are shown in Fig. 4.Based on the established characteristics of the abandoned pit lake at Nyala Mine, the major safely issues of the excavation were mainly associated with high pit walls characterised by vertical to near vertical slope angles and thick sticky mud at the pit floor. That there is continuous exposure of both animals and members of the community to the hazardous features of the abandoned open excavation is creating a greater potential for adverse effects to public safety and health.

(a)

(b)

Fig. 2. The abandoned Nyala Mine pit lake, (a) animals from drinking water in the pit and (b) skeleton of the dead animal trapped in mud at the pit floor

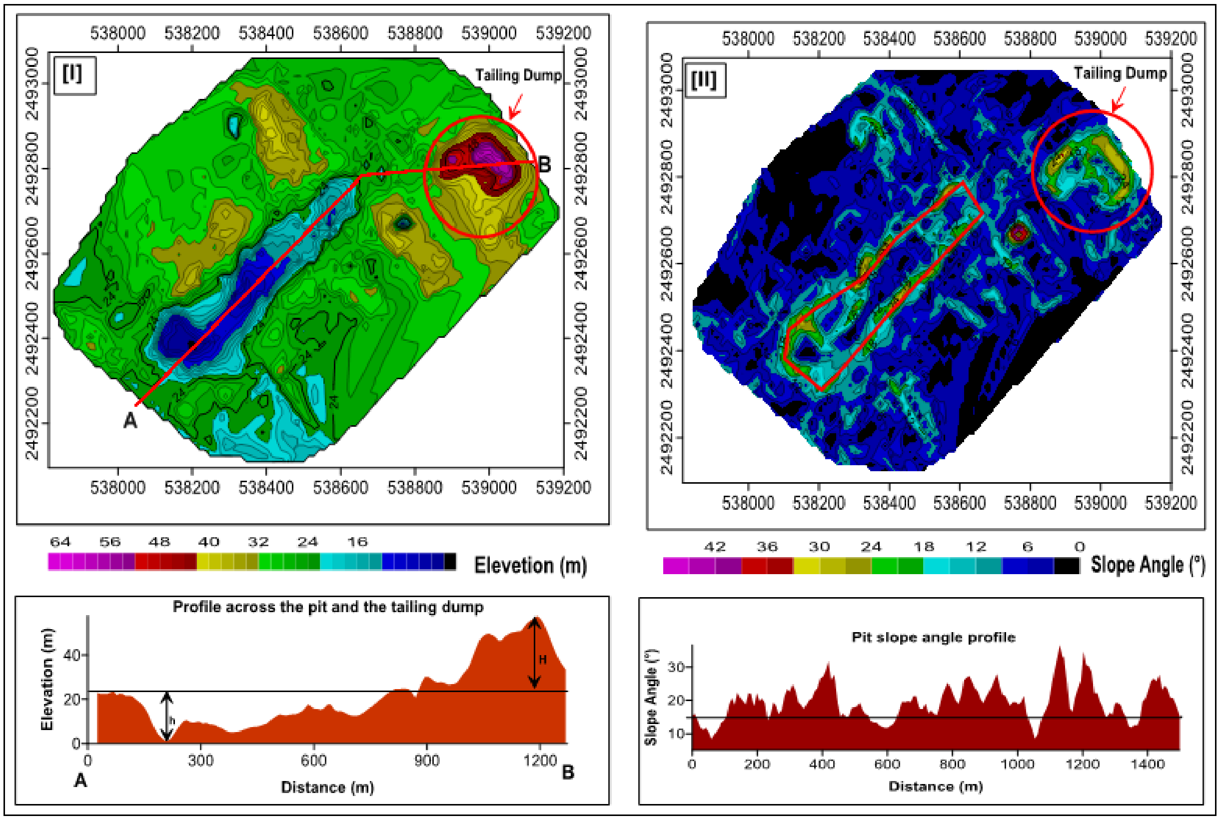

Fig . 3. The pit terrain characteristics, (I) is the topographic map of the pit and its surroundings and (II) depicts the terrain slope angle

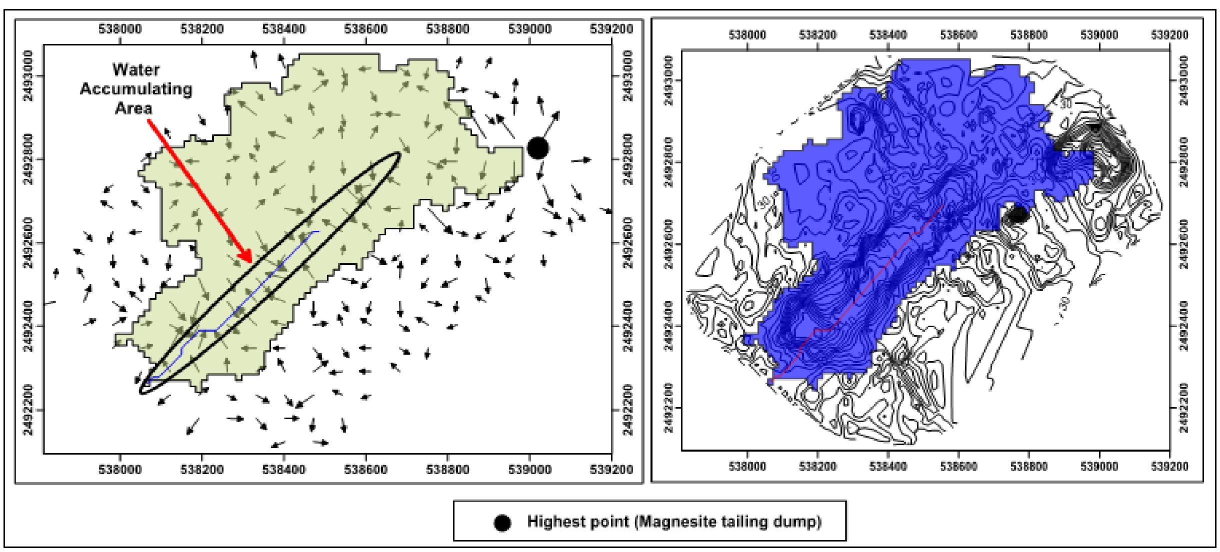

Fig.4.An illustration of watershed areas in the hazardous pit

In order to control the degree of fine sediments deposition in the pit floor while improving the stability or safety of the pit walls, grading of the pit slopes was found appropriate. According to the mine rehabilitation guideline by the Chamber of Mines of South Africa and Coaltech (2007), reshaping of pit slopes is a temporal strategy used to control the amount of erosion on pit slopes; hence the establishment of vegetation on pit slopes is to be encouraged to provide permanent erosion control measures. The analysis of the abandoned excavation slopes using the terrain slopes models indicated that more stable pit slopes with least amount of erosion effects can be achieved by grading the slopes to less than 14° (25% grade or 4:1 flatter). On this, the measured average height of the pit walls (22 m) indicated that the walls are reshaped or redesigned with about 1 m reverse bunch (inclined 2% to 3% towards the protected inflow channels) contracted half distance from the overall pit slope toe and crest as shown in Fig.5. The installation of stone check dams with the aim of preventing further erosion along the diversion channels and reverse bunch that feed to the gabion protected inflow channels is proposed.

The water in the pit lake was found to be strongly alkaline with an average pH value of 9.8 and electrical conductivity of 2.3 mS/cm. Chemical analysis of the water in the pit lake showed that the water is characterized by high content of Mg (±67.9 ppm), K (±87.2 ppm), F (±1.1 ppm) and Cl (±169.6 ppm). Comparison of the water quality results with the Department of Water Affairs and Forestry (DWAF) standard for domestic use of water revealed that these elements were above the permissible levels (see Table 1). In addition to chemical characteristics, the water in the lake was found to be characterised by dense growth of algae.

Chemical analysis of the water from the abandoned Nyala Mine pit lake indicated that parameters such as pH and concentrations of fluoride (F), chloride (Cl), magnesium (Mg) and potassium (K) were above the DWAF permissible limit for domestic use of water. The most common and well known health problem of high fluoride intake is its impact on bones and teeth. However, there are other health problems of excessive intake of fluoride which are receiving less attention. These were outlined by Shrivastava and Sharma (2012) to be fibre degeneration, low hemoglobin levels, deformities in red blood cells (RBCs), excessive thirst, headache, skin rashes, nervousness, neurological manifestation, depression, gastro-intestinal problems, urinary tract malfunctioning, nausea, tingling sensation in fingers and toes, repeated abortions, male sterility. According to the South African Department of Water Affairs standards for domestic use of water, if the water in the pit lake is consumed by humans, it is expected that the determined fluorite concentration of 1.1 ppm cause slight mottling of dental enamel in sensitive individuals. On the other hand, the chloride (169.63 ppm), magnesium (67.85 ppm) and potassium (87.16 ppm) concentrations were found to be without any aesthetic and health impact when consumed by human. However, the chloride levels have potential to cause increased corrosion rate in domestic appliances, while Mg had potential to cause slight scaling problems. In addition, potassium (K) concentration was found undesirable for infant and persons with renal diseases. The water pH value of 9.8 was found to be within the range characterized by increased probability of toxic effect associated with deprotonated species and also bitter taste of water (DWAF, 1996). The corresponding electrical condictivity (EC) of 2.32 mS/cm was measured and found to be within the permisable limit for domestic use of water. In addition, the witnessed growing algae in the water present slight limits in the use of the pit lake for recreational purposes thus it makes the water to be visually unappealing with increased unpleasant odour which might be due to algae decaying in the water.

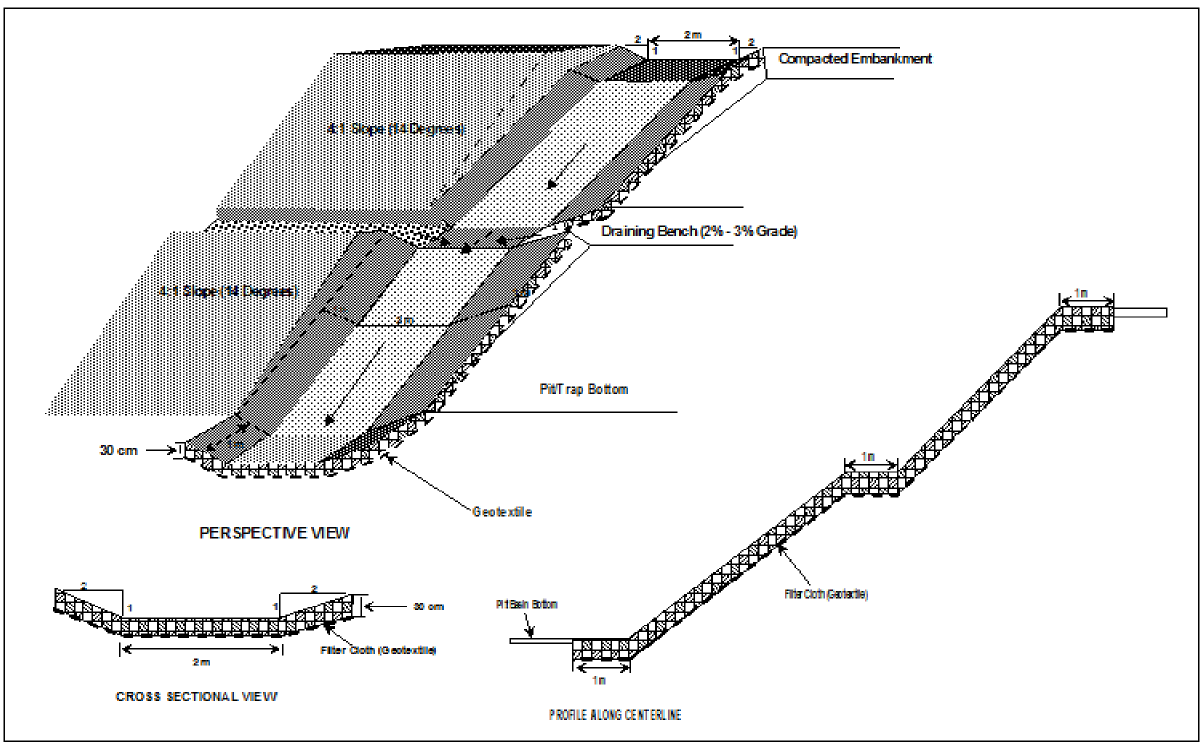

Fig. 5. Gabion Inflow protection details: not to scale

Table 1. Chemical composition of water in an abandoned magnesite excavation

♠Elements	Mean (ppm)	DWAF Limit (ppm)	♦Elements	Mean (ppm)	DWAF Limit (ppm)
F^-	1.10	1.0	Na^+	8.22	100
Cl^-	169.63	100	Ca^{2+}	15.67	32
NO^{3-}	0.76	6	Mg^{2+}	67.85	30
PO_4^{3-}	-0.04	-	K^+	87.16	50
SO_4^{2-}	0.71	200	Fe^{3+}	-0.27	0.1

♠Anions concentration and ♦Cations concentration

CONCLUSION

Based on the abandoned mine site field description, major safety threatening features of the Nyala Mine Pit Lake are sticky mud in the pit floor and few unstable pit walls. Modeling of the terrain parameters showed that the pit covers an area of approximately 105685 m^2 (≈ 10.57 ha) and it attain the maximum depth of 22m with some of the pit slope angles being greater than 40° (during the site visit few pit wall slopes were measured and found to be up to 87°). In addition, the pit was found to be receiving high runoff from high grounds disturbed by mining and the tailing dump found near the abandoned excavation was identified as the major source of fine material that is easy eroded and deposited in the pit floor by runoff water. Consequently, in ensuring safe access to the water in the pit lake, reshaping of unstable pit walls to the gradient of about 14° (4:1 slope ratio) and installation of erosion control measures such a gabion protected inflow channels and stone check coupled with re-vegetation of pit slopes to limit or eliminate the deposition of fine sediments in the pit floor was found appropriate.

Chemical analysis of certain parameters of the water samples from the pit lake showed that the water can be used for domestic purposes and as drinking water by animals. However, its use for domestic purposes should be considered with caution because of the high concentration of F, Cl, Mg and K; that were above the permissible limit.In addition, it is worth mentioning that rehabilitating old mines excavation can be a daunting task but with the right strategies and tools, abandoned mining pits can be transformed from lifeless landscapes into prosperous and beneficial end-uses. The approach used in conducting this study will serve as a framework or guide for characterisation and rehabilitation of abandoned mine excavation elsewhere where conditions similar to those at Nyala Mine exists.

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