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Assessment of Safety Status of Open Excavations and Water Quality of Pit Lake at Abandoned Nyala Mine in Limpopo Province of South Africa

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Abstract The study focused on assessment of safety status of open pit and suitability of water in Nyala Mine Pit Lake for domestic uses. The approach used in the investigation involved field description of the lake, modelling of surface runoff to the pit and chemical analysis of the water. It was found that the pit accumulates runoff water from high grounds along the northern part of the excavation. The water in the pit 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.
Keywords mine pit lake, water quality, public safety, abandoned mines

Introduction

Mining operations degrade large areas of land and replaces the existing ecosystem with large volume 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 of the impact of mining on 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 is rated the most hazardous mine feature to both the environment and the members of the public and animals (Mhlongo et al., 2013b). 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. However, these uses of the pit lake depend so much on the quality of the water and safe accessibility. This research therefore, is aimed at assessing the safety status of open excavation and water quality of the pit lake at the abandoned Nyala mine.

Description of the Study Area

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. The mine lease area and the Zwigodini area at large is characterised by fairly flat topographic relief 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 ℃ and the minimum temperatures that range between 20 ℃ and 25 ℃ during the winter season. There are no flowing streams around and, as a result, the community around the mine rely on ground water resources for domestic uses.

Methods and 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 pit lake and its uses and associated physical hazards. The land elevation data collected using an RTK GPS System was used in the modeling of watershed areas of the mine landscape. The simulation of surface water flow into and around the pit was achieved by superimposition of the created 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 and Discussion

Field Description of the Pit Lake

The Nyala Mine pit lake was found to extend laterally for more than 600 m at an average width of 113 m. The height of the pit walls were measured and found to be ranging from 12 to 44 m whilst the slope angles varied from 20° to 87°. Most of the walls of this pit 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 as drinking water by animals (see fig. 1a), 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. 1b.

Accumulation of Runoff Water in the Pit Lake

The modelling of the watershed areas around the abandoned pit at Nyala Mine revealed that the pit 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 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. 2.

Fig.1 *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*

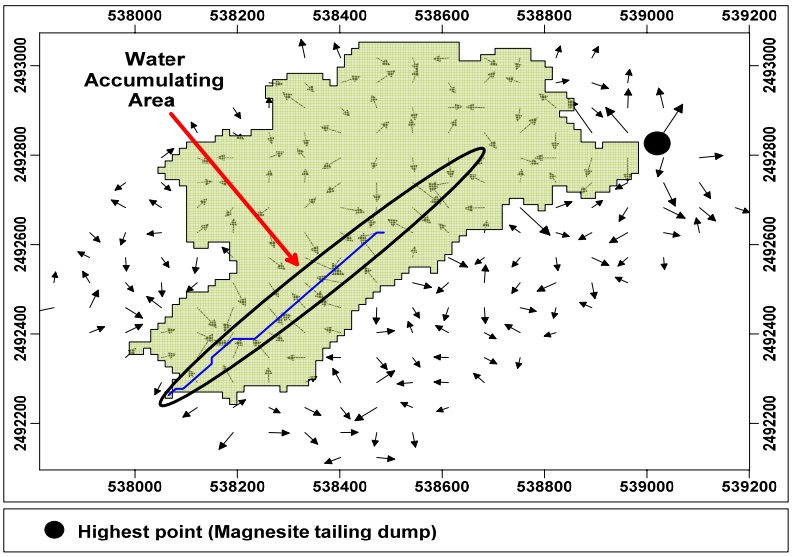

Fig. 2 *An illustration of watershed areas in the hazardous pit*

The Quality of Water in the Pit Lake

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^{2+} (±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 fiber degeneration, low haemoglobin 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 course 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 corrosponding 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.

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

Concentration	Mean (ppm)	DWAF Limit (ppm)	Concentration	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

Conclusions

The site description showed that the major safety threatening features of the pit lake are sticky mud in the pit floor and few unstable pit walls. On the other hand, the surface water flow model indicated that the pit receive high runoff from high grounds disturbed by mining. This contributes substantially to fine sediments deposition in the pit floor thus increasing physical hazards associated with sticky mud. Therefore, in ensuring safe access to the water in the lake, reshaping of unstable pit walls and installation of erosion control measures to limit or eliminate the deposition of fine sediments in the pit floor should be considered.

Animals drink the water in the pit, however, its use for domestic purposes should be considered with caution because of the high concentration of F, Cl, Mg and K; as well as high pH value that were above the permissible limit for domestic use of water in South Africa. The presence of algae in the pit lake also precludes the use of this water for domestic purposes. 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.

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