Mitigation measures for the acid mine drainage emanating from the Sabie Goldfield: Case study of the Nestor Mine

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Abstract

Acid mine drainage (AMD) from the Nestor Mine Tailings Storage Facility (MTSF) is a serious threat to the surrounding ecosystem, particularly the Sabie River system. This study aims to develop mitigation measures for AMD from the Nestor MTSF (NTS) using materials from the Glynns Lydenburg MTSF (GTS). Two mixtures were prepared using samples from the Nestor MTSF and the Glynns Lydenburg MTSF, namely COM25, which contained 25% w/w GTS and 75% w/w NTS. The second mix, called COM50, contains 50% GTS and 50% NTS. The static test was used to estimate the acid generation probabilities of the samples for COM25 and COM50. While the paste pH of the Nestor sample was acidic (2.5), the paste pH of the Glynns Lydenburg sample was relatively high (7.7), indicating that it can neutralize acid. The paste pH values of COM25 and COM50 were 5.1 and 6.1, respectively, indicating that both mixtures can generate alkalinity. In addition, the mineralogy of the Nestor MTSF sample consists of the primary acid-producing mineral pyrite. However, the primary acid-neutralizing mineral dolomite is present in the Glynns Lydenburg sample. According to the findings, Glynns Lydenburg materials can neutralize AMD from Nestor MTSF.

Keywords: Nestor mine, acid mine drainage, sustainable treatment techniques, Sabie river system

Introduction

Acid mine drainage (AMD), which has a low pH and high concentrations of dissolved metal species, has the potential to endanger South Africa's water resources, alongside other types of pollution that contribute to water quality degradation. Improved methods for estimating the costs of various AMD treatment options are required to ensure sufficient funding and effective treatment strategies.

The Nestor Mine Tailings Storage Facility (MTSF) is severely weathered and is the site of illegal mining. During the rainy season, these materials are washed downstream into the Klein Sabie River, a tributary of the Sabie River system. The Glynns Lydenburg MTSF, which has a vegetation cover and is not weathered, is located approximately 2 km southwest of the Nestor MTSF (Lusunzi 2018). Previous studies have shown that the Glynns Lydenburg MTSF produces alkalinity, while the Nestor MTSF produces acidity (Lusunzi et al. 2017; 2019). Two types of water have been identified: AMD with elevated trace element concentrations from the Nestor MTSF and neutral drainage with low trace element concentrations along the Sabie River system (Lusunzi et al. 2020). Historically, mining influenced water has been treated and managed using a variety of active and passive remediation methods. Even though there are currently available remediation techniques, treating AMD remains difficult. Due to the need for sustainable AMD treatment methods, resource recovery and water reuse have received much attention (Naidu et al. 2019). However, site-specific, long-term AMD treatment solutions must be developed. The goal of this research is to develop and evaluate AMD mitigation measures for the Sabie Goldfield, with a particular emphasis on the Nestor MTSF. The research will also provide extensive data sets for future initiatives, such as mathematical modelling of AMD.

Study Area

The Nestor and Glynns Lydenburg mine tailings storage facilities (MTSFs) are located in the Sabie Goldfield in South Africa's Mpumalanga Province (Fig. 1). They are geologically part of the Transvaal Supergroup and are found in the eastern part of the Kaapvaal craton. The Glynns Lydenburg MTSF is located in the Malmani Subgroup of the Chuniespoort Group, and gold was extracted from the dolomite host rock. Gold was mined from shale host rocks at the Nestor MTSF, which is located within the Black Reef Quartzite Formation.

Methods

The Nestor MTSF (NTS) and the Glynns Lydenburg MTSF (GTS) each provided two bulk samples. A total of 20 kg of composite tailings samples were collected from the MTSFs' bases and placed in plastic buckets that were tightly closed before being transported to the North-West University laboratory for preparation before analysis. To limit the degree of pre-oxidation, the samples were dried in a drying furnace at 40 °C for 24 hours and stored in airtight containers according to the ASTM D5744-18 standard. The samples were sieved through a 200-mesh sieve to obtain samples with particle sizes less than 75 µm to perform the following tests. Using samples from the Nestor MTSF (NTS) and the Glynns Lydenburg MTSF (GTS), two mixtures were created. COM25 is the name given to a mixture that contains 25% GTS and 75% NTS. COM50 is the name given to the second mixture, which contained 50% GTS and 50% NTS. The acid generation probabilities of the NTS and GTS samples for COM25 and COM50 were estimated using the same static tests: acid-base accounting (ABA) and net acid generation (NAG) (Stewart et al. 2006).

The collected tailings samples were

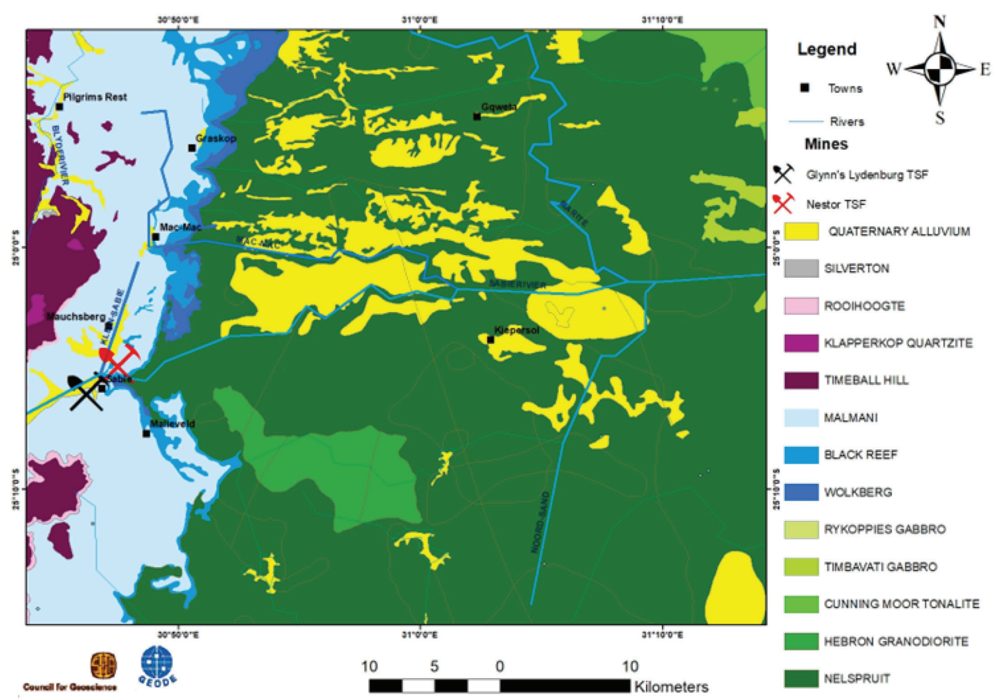

Figure 1 Location of the Nestor and Glynns Lydenburg Mine Tailings Storage Facilities

analyzed using acid base accounting (ABA) and X-ray diffraction (XRD) at the Council for Geoscience laboratory. The Modified Sobek Methods as described by Lawrence (1990) and Weber et al. (2005), were employed. X-ray diffraction measurements were conducted on a BRUKER D8ADVANCE instrument equipped with a 2.2 kW Cu long fine focus tube (Cu Kα, λ = 1.54060) and a sample changer with 90 positions. The system included a LynxEye detector with a 3.7° active area. Samples were scanned from 2 to 70° 2θ at a rate of 0.02° 2θ steps per 0.5 s with generator settings of 40 kV and 40mA. The phase identification was done using the BRUKER DIFFRACPlus – EVA evaluation program. Routinely, phase concentrations were determined as semi-quantitative estimates (with an accuracy of ± 5%) using the RIR (Reference Intensity Ratio) method and relative peak heights/areas proportions (Brime 1985).

Results and Discussion

An innovative method of dealing with acid mine drainage (AMD) using low-cost, locally available materials was used. This is described below.

Acid-Base Accounting

The acid-base accounting results of samples from the Nestor and Glynns Lydenburg mine tailings storage facilities (MTSFs) are shown in Table 1. The Nestor MTSF sample (NTS) has a low paste pH of 2.5, which indicates that it is acid-generating and may contain high concentrations of stored acidity. In comparison to the Glynns Lydenburg MTSF sample, all Nestor MTSF samples have high sulfur concentrations ranging from 0.25 to 0.43. Furthermore, the sample NTS lacks an acid-neutralizing capacity (ANC) and has a high maximum potential acidity (MPA) value of 13 kg H_2SO_4/t. The Glynns Lydenburg MTSF (GTS), on the other hand, has a relatively high paste pH of 7.7, indicating that it is most likely a non-acid generating sample. It also has a very high acid-neutralization capacity (ANC) of 184 kg H_2SO_4/t, indicating a high concentration of acid-neutralizing minerals. The negative net acid-production potential (NAPP) of samples GTS, COM25, and COM50 indicates that they have no acid-production capability. COM25 and COM50 have paste pH values of 5.1 and 6.1, respectively, indicating that both mixtures may produce alkalinity. These two mixed samples have ANC values of 56 and 96 kg H_2SO_4/t, which are relatively high in comparison to their MPA values. The mixtures could be used to treat or prevent AMD emanating from the Nestor MTSF. An ANC/MPA ratio of 2 or greater generally indicates that the material has a high probability of remaining pH neutral. As a result, the Glynns Lydenburg MTSF sample, as well as COM25 and COM50, are likely to keep the acid from the Nestor MTSF neutralized.

Fig. 2 depicts the acid buffering characteristic curves (ABCC) of COM25, COM50, and GTS (AN). The Nestor MTSF (GTS) sample lacks an ABCC because it lacks acid-neutralizing capabilities. The mixed sample, COM25, COM50, and the Glynns Lydenburg (GTS) sample can neutralize 50 and 90 kg H_2SO_4/t before the pH of the solution drops substantially below 2,5, which closely corresponds to the ANC results determined using the ABA method (Table 1). When the pH of mine tailings falls below 4 due to ferrous iron (Fe^{2+}) oxidation of sulfide minerals, the rate and amount of acid produced increases dramatically. Thus, the effective or freely available acid-neutralizing capacities refer to the amount of acid neutralized prior to the drop in pH of the

Table 1 *Acid-base accounting results*

Sample ID	Paste pH	ANC (kg H_2SO_4/t)	$S_{(Total)}$	MPA (kg H2SO4/t)	NAPP (kg H_2SO_4/t)	$R_{ANC/MPA}$
NTS	2.5	0	0.43	13	13	0
GTS	7.7	184	0.07	2	–182	92
COM25	5.1	56	0.34	10	–46	6
COM50	6.1	96	0.25	8	–88	12

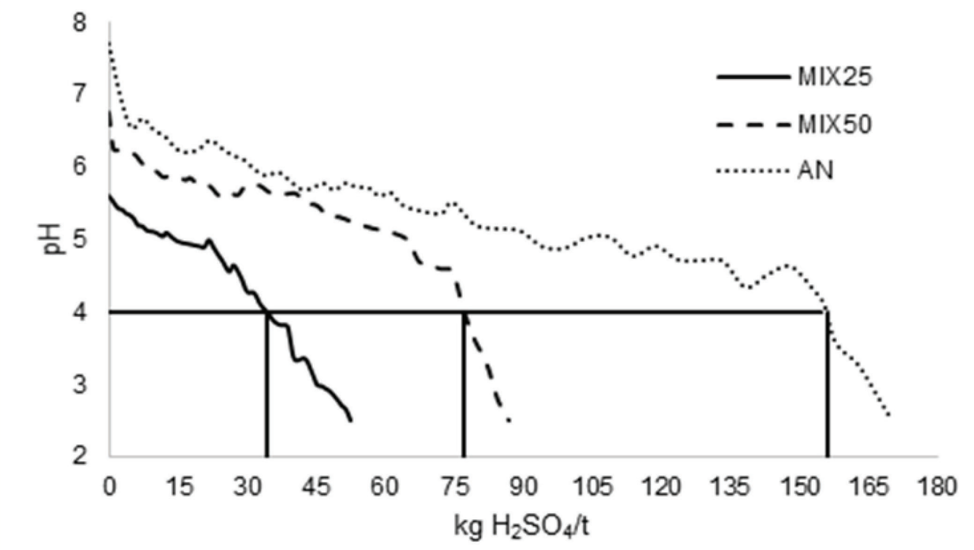

Figure 2 *Acid buffering characteristic curve (ABCC) curves of samples COM25, COM50 and GTS*

solution to 4. Before the pH of the solution drops to 4 (Fig. 2), samples COM25, COM50, and GTS neutralize 35, 77, and 155 kg H2SO4/t, respectively. A substantial portion of the ANC determined by the ABA method is readily available for acid neutralization.

When the ANC of each sample measured using the ABCC and the ABA methods are compared (Table 2), a substantial portion of the ANC measured using the ABA method is freely accessible for acid neutralization. The high availability of acid neutralization is most likely due to a high concentration of highly reactive carbonate minerals such as calcite or dolomite. The ANC of COM25, COM50, and GTS are not overestimated and will be readily available for acid neutralization.

The acid-generating capabilities of the Nestor MTSF (NTS), COM25, COM50, and Glynns Lydenburg MTSF (GTS) samples can be classified as potentially acid forming (PAF), not acid forming (NAF), NAF, and NAF with high confidence using the NAPP, NAG pH, and the classification criteria summarized in Table 3. The tailings from the Nestor MTSF have a positive NAPP, which indicates that they are potentially acid forming. Conversely, the material from the Glynns Lydenburg MTSF, COM25 and COM50 are potentially non-acid forming as they have a negative NAPP.

NTS, COM25, COM50, and GTS have pH values of 2.7, 4.9, 5, and 5.9, respectively, and NAG values of 6.9, 0, 0, and 0 kg H_2SO_4/t. As a result of the NAG results, NTS is a potential acid-forming sample, with the potential to release up to 6.9 kg of sulfuric acid per ton of material. Table 3 summarizes the non-acid forming (NAF) classification criteria for COM25, COM50, and GTS.

Mineralogy of the tailings

The mineralogical composition of the tailings collected from the Nestor (NTS) and Glynn's

Table 2 *Comparison of ANC calculated and at a pH of 2.5 and 4.0*

Sample	ANC (ABA) (kg H_2SO_4/t)	ANC ($ABCC_{pH = 2.5}$) (kg H_2SO_4/t)	ANC ($ABCC_{pH = 4}$) (kg H_2SO_4/t)
COM25	56	53	35
COM50	96	87	77
GTS	184	170	155

Table 3 Final classification

Sample	NAPP (kg H_2SO_4/t)	NAG-pH	Classification
NTS	13	2.7	PAF
COM25	−46	4.9	NAF
COM50	−89	5.0	NAF
GTS	−182	5.9	NAF

Lydenburg (GTS) MTSFs is shown in Table 4. The acid-generating sample (NTS) consists primarily of quartz, mica, and pyrite in ascending order, with minor concentrations of the secondary mineral goethite. Pyrite is the primary acid-producing mineral in the NTS. The Glynns Lydenburg MTSF sample (GTS), on the other hand, is composed of quartz as the main mineral and the acid-neutralizing mineral dolomite. Furthermore, the secondary mineral goethite is more abundant in the Glynns Lydenburg MTSF than in the Nestor MTSF, which is consistent with geochemical data indicating a higher concentration of Fe_2O_3 in the Glynns Lydenburg MTSF. The geological setting of the two MTSFs has the greatest influence on their differing mineralogical composition.

Conclusions

Based on the results of this study, remediation of the Nestor MTSF should be given the highest priority. Given its location and geochemistry, the tailings material from the Glynns Lydenburg MTSF could be used as a cover for potential vegetation growth in the Nestor MTSF. Solid mining waste can be effectively isolated from contamination by capping or covering it. As a result, the remediation of the acidic Nestor MTSF should include capping it with Glynns Lydenburg MTSF materials. Given that the alkaline tailings are approximately 2 km from the Nestor MTSF, this would be a cost-effective option. In addition, the rehabilitation of the Nestor MTSF will create jobs for the local community. This will bring additional economic benefits. The current study has limitations, including the lack of gold assays on the tailings to assess their potential for gold recovery. As a result, both the Nestor and Glynns Lydenburg MTSFs should be evaluated and characterised for gold recovery potential prior to the commencement of any remediation work.

Recommendations

The study provides a comprehensive assessment of the effects of AMD and proposes innovative and sustainable solutions to address this issue. It offers valuable insights into effective AMD management through case studies and applied methodologies, with important implications for environmental remediation and policymaking in mining areas. Acidic Nestor MTSF can be rehabilitated using the alkaline tailings materials from the Glynns Lydenburg MTSF.

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Table 4 Mineralogy of the tailings

Sample ID	Quartz (wt. %)	Dolomite (wt. %)	Mica (wt.%)	Pyrite (wt.%)	Goethite (wt.%)
NTS	80.5	ND	17.9	0.1	1.5
GTS	59.7	29.4	8.0	ND	2.9

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