Macrothink Institute™

International Journal of Regional Development
ISSN 2373-9851
2025, Vol. 12, No. 1

Assessment of the Suitability of Selected Organic Waste for Improving Acid Mine Drainage Treatment in Tanzania

Alexander Marwa

School of Engineering and Environmental Studies

Ardhi University, Tanzania

E-mail: alex.marwa@gmail.com

Received: April 28, 2025 Accepted: May 20, 2025 Published: May 27, 2025

doi:10.5296/ijrd.v12i1.22825 URL: http://dx.doi.org/10.5296/ijrd.v12i1.22825

Abstract

One of the most serious environmental issues associated with mining operations is the generation of acidic mine drainage (AMD), which contains low pH, dissolved metals, and sulphate. The aimed of this was to assess the suitability of locally available organic wastes for improving acid mine drainage treatment. In this study, four containers as reactors containing cow manure (S1), chicken manure (S2), sawdust (S3), and a mixture (S4) of S1, S2, and S3 were used as the organic wastes for anaerobically treating AMD. This study revealed that the pH increased from 3.1 to 7.6 in all reactors and the highest sulfate removal (95%) was observed in the mixed organic waste reactor (S4). Similarly, a high percentage of Mn removal of >84% was observed in all reactors, while this study also found poor removal of zinc in S3 at 22%. In general, this study showed that the mixture of different organic waste sources improved the removal efficiency of Zn by 73%. The results obtained give a promised using of available organic waste as better technology option for treatment of AMD water from mining operations.

Keywords: acid mine drainage, treatment, organic wastes, sulphate, heavy metals

1. Introduction

Acid mine drainage (AMD) has become a serious issue worldwide as it represents the environmental problem related to large and small-scale mining operations (Quicasan et al., 2017). AMD is commonly known as a waste or product of the mining and mineral processing industry and its context has been reported by various authors (Johnson, 2003). Therefore, concentrations such as dissolved metals, high sulphate content and low pH are one of the classifications or levels of AMD that pose a serious problem for the environment and sometimes lead to fatal effects that damage biodiversity and aquatic ecosystems (Ngure et al., 2014). Mining activity is a significant contributor to metal concentration due to the discharge and natural spread of mining waste by wind, water and rain into aquatic ecosystems (Elouear et al., 2016). One of the recommended and promised technologies for using biological methods to treat AMD water is the use of sulfate-reducing bacteria (SRB) (Gazea et al., 1996). By using SRB, organic waste as an organic carbon source (electron donor) can be oxidized to bicarbonate and available sulfate (electron acceptor) can be reduced to hydrogen sulfide (Johnson and Hallberg, 2005). This organic waste can treat AMD due to SRB presented within the waste materials (Santim et al., 2010; Othaman et al., 2015; Lakaniem et al., 2020). SRBs are a viable alternative technology to treat AMD. Therefore, for the SRB to survive, they need organic carbon sources (Neculita et al., 2007). Three organic substrates were used included sawdust, leaf compost and poultry manure as substrate for SRB in the treatment of water heavily contaminated with AMD (Neculita et al., 2007). After 120 days of treatment, sulphate reduction decreased from 5500 mg/L to 1 mg/L and metal removal of 96.9-99.8% was achieved.

On the other hand, the availability of SRB in bioreactors containing organic waste can increase the pH of AMD water and lower the dissolved metals through precipitation as metal sulfides (Neculita et al., 2007). Most studies have shown that mixtures of different natural organic materials enhance AMD treatment performance better than single-source materials (Zagury et al., 2006). In the performance of bioreactors using organic waste, Gibert et al., 2004 reported that an increase in residence time is associated with an increase in sulfate removal. Other studies found that the availability of sulfate and organic carbon affects the level of microbial activity and thus improves performance. This is because AMD contains a high concentration of sulphate but little dissolved organic carbon (Kolmert and Johnson, 2001).

The key factor in determining organic substrate performance is the release rate of available organic carbon for SRB growth. It has been reported that the combined use of cellulosic materials (wood, straw, hay and organic materials (compost, manure)) could lead to higher efficiency in AMD treatment (Neculita & Zagury, 2008). Characterizing and testing the potential use of various organic wastes for AMD treatment is imperative. Munawar and Riwandi (2010) found that natural organic matter varies in properties and may also affect remediation properties differently. For example, Abou-Hussein, 2002 reported that organic materials can increase nutrients, however when the mixture of cow and chicken manure used improves treatment performance. Another study by Salary (Munawar and Riwandi, 2010) reported that the use of sawdust did not raise the pH to the acceptable level. Similarly, other authors reported that sheep manure application increased electrical conductivity (Elouear et al., 2016). However, other studies (Dube et al., 2024) indicated that the importance of current and future research on the developing novel adsobents for treatment of acid mine drainage. In addition, other studies have used only goat manure for effectiveness of AMD treatment (Othamn et al., 2015). The aimed of this study was to evaluate the potential use of selected locally available various organic wastes for AMD treatment.

2. Method

2.1 Organic Wastes and Their Characterization

Four types of organic waste were used in this study: S1 = cow manure; S2 = chicken manure; S3 = sawdust (eucalyptus); S4 = mixture of S1, S2 and S3. These organic wastes were locally available to the study area. All organic wastes were pulverized to less than 2 mm and sieved (Zagury et al., 2006) and measured for pH, EC, TOC and moisture content. pH was measured using a 1:1 solid/liquid ratio (ASTM, 2001) and a 378 HACH pH meter. The moisture content was analyzed by measuring the wet weight of the organic substrate in a crucible and drying at $105^{0°}$C for 24 hours, then allowed to cool and then measuring the dry weight.

2.2 Experimental Setup and Description

The batch test setup included four plastic containers as anaerobic reactors with a capacity of 5 L. Each 500g of organic waste was ground into powder form to fill the reactor and 3000 mL of fresh AMD water obtained from North Mara Gold Mine was poured in. The mixing ratio used in the batch setup was 1:6 (w/v), representing one part organic waste to six parts acid mine drainage (AMD), as adopted from Neculita and Zagury (2008). The setup consisted of four reactors: S1 = 100% cow manure; S2 = 100% chicken manure; S3 = 100% sawdust; S4 = mixture of all three in equal proportions.

2.3 Water Sampling and Analysis from Batch Reactors

Water samples were collected from the experimental setup batch reactors over a period of 63 days. These samples were analyzed for physiochemical parameters (pH, EC, Zn, Mn and SO_4). Physical parameters (pH, EC) by the potentiometric method (Sension 378 HACH), manganese by the periodate oxidation method (HACH, DR/4000U spectrophotometer), zinc by the AA spectrometer (Analyst 100, PerkinElmer Instrument) and sulphate by the turbidimeter method.

3. Results and Discussion

3.1 Characterization of Organic Waste and AMD

The characterization of the selected organic materials and AMD is given in Table 1 and Table 2. The pH of the organic materials tested (S1, S2, S3 and S4) ranged from 5.7 to 8.3, with sawdust (S3) showed the lowest pH, while cow manure (S1) and chicken manure (S2) showed the highest pH. In addition, the total organic carbon in the reactors (S1, S2, S3 and S4) is 73.94%, 24.07%, 51.02% and 43.11%, respectively. In addition, the AMD water has a pH of 3.1 and heavy metals (Mn and Zn) are 55 and 7.7 respectively, while the sulphate was 2277 mg/L (Table 2).

Table 1. Characteristics of organic wastes used in treatment of AMD

Parameters	S1	S2	S3	S4
pH	8.3	7.45	5.7	7.7
EC (µS/cm)	3200	1150	2500	4570
TDS (mg/L)	1670	610	1250	2650
Salinity (ppt)	2.3	5.2	1.6	2.5
Total Organic Carbon (%)	73.94	24.07	51.02	43.11
Moisture content (%)	57.75	10.45	48.08	14.98

Note. S1=100% cow manure, S2=100% chicken manure, S3= 100% sawdust, S4= mixture of S1, S2 and S3.

Table 2. Characteristics of AMD Used in the Batch Reactors

Parameters	**Value**
EC (µS/cm)	2430
TDS (mg/L)	1304
pH	3.1
Mn (mg/L)	55
Zn (mg/L)	7.7
SO_4^{2-} (mg/L)	2277

A high pH was observed in the reactor (S1) containing cow manure. Other studies have similarly reported that a higher pH was found after using composted animal manure (Scharenbroch, 2009). The observation from reactor (S1) also showed a high EC. Dikinya and Mufwanzala, 2010, reported that applying animal manure to the soil resulted in a higher EC value. Higher EC values were also reported by Loper et al., 2020, in soil after using animal manure. In this study, it was observed that AMD is characterized by low pH, high electrical conductivity (EC), high dissolved metals, and high sulphate. Parameters to consider as characteristics of AMD include low pH associated with metal leaching (McCarthy, 2011). Lewis, 1997 reported that metal leaching from AMD is usually associated with high concentrations and toxic heavy metals. Other studies reported that AMD is characterized by low pH, high dissolved metals, high EC and sulfate levels (Gaikwad, 2008).

3.2 Physiochemical Characterization in Batch Reactors during 63 Days of AMD Treatment

The water quality results after treatment in reactors presented in Table 3 and Table 4. The pH in the reactors improved from 3.1 to 7.2 in S1, 3.1 to 7.6 in S2, 3.1 to 4.8 in S3 and 3.1 to 7.3 in S4. However, the electrical conductivity in the reactors has increased compared to the original (Table 1). This study showed that the manganese removal in the reactors (S2 and S3) was higher than in other reactors. In addition, zinc reduction was poor in both reactors (S2 and S3). This study observed an increase in electrical conductivity in all reactors after 63 days of treatment. Figure 1 showed that the pH of AMD increased from day 7 to 63 and the pH of the chicken manure in reactor S2 was higher than the rest.

Table 3. Water quality results after 63 days batch reactor experiment for AMD treatment in different organic wastes

Batch Reactor	pH	Ec (µS/cm)	SO_4^{2-}(mg/L)	Mn (mg/L)	Zn (mg/L)
Cow manure (S1)	7.2	4640	155	1.6	3.2
Chicken manure (S2)	7.6	7452	161	0.005	4
Eucalyptus saw dust (S3)	4.8	2570	478	0.005	6
Mixed [S1+S2+S3](S4)	7.3	6150	108	9	2.1

Table 4. Metal removal efficiency during 63 days in batch reactors for AMD treatment

Batch Reactors	% Improved		
	SO_4^{2-}	Mn	Zn
Cow manure (S1)	93	97	58
Chicken manure (S2)	92	100	48
Eucalyptus saw dust (S3)	79	100	22
Mixed [S1+S2+S3] (S4)	95	84	73

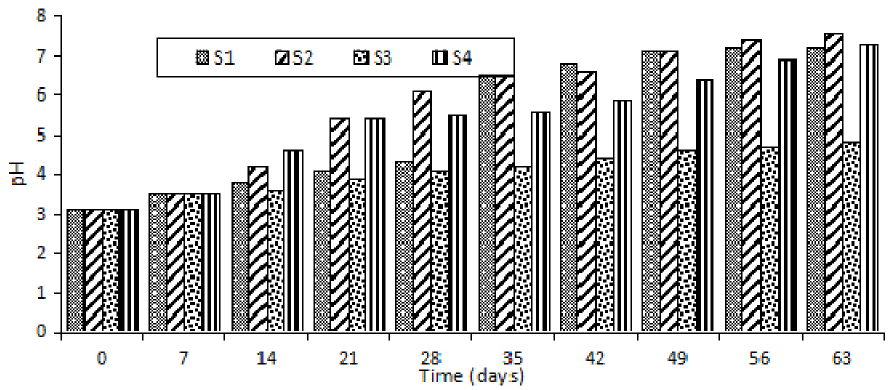


Figure 1. Variation of pH in batch reactors during treatment of AMD

Highest of pH in the reactor contained chicken manure was most likely due to its high organic content when dissociation increases alkalinity in AMD water, since the availability of organic contents influences microbial activities that consume organic components and produce bicarbonates that increase alkalinity (Ludwig et al., 2002; Shabalala, 2013). AMD from mining operations contains very low concentrations of dissolved organic carbon, which can impede the rise in water pH (Zagury et al., 2006).

3.3 Sulphate Reduction in Batch Reactors for AMD Treatment

Sulphate reduction and its removal efficiency presented in Figure 1 and Figure 2. The results of this study showed that sulphate reduction in reactor (S4) was higher compared to other reactors (Table 1 and Table 2). For most reactors it was observed that performance increased with increasing contact time. However, from day 56, the reactors (S1, S2 and S3) started to reduce their performance. Most reactors showed a strong reduction from day 28 (Figure 2). In additional, the lowest sulfate removal performance was obtained in reactors (3) (Figure 3).

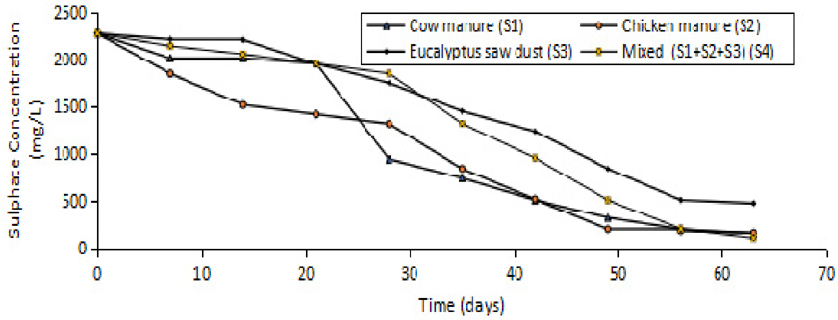


Figure 2. Variation of sulphate concentration in batch reactors for treatment of AMD

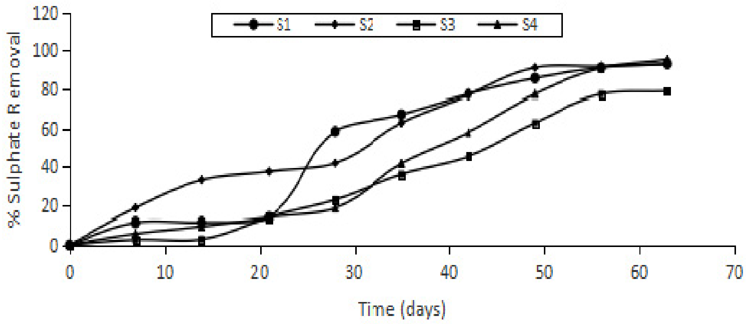


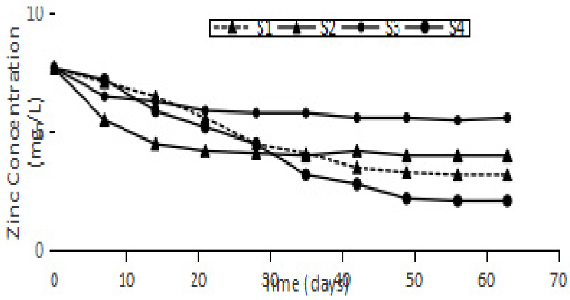
Figure 3. Variation of sulphate removal efficiency in batch reactors for treatment of AMD

This study also showed that the highest sulphate reduction performance in the reactors is obtained when mixed with other organic substrates. The results obtained aligned with Amos and Younger (2003) observed that sulphate reduction occurs better when cow manure is mixed with other organic wastes. Similarly, according to Zagury et al. (2006) it was observed that the mixture of organic wastes promotes sulfate reduction more effectively than individual substrates. The key factor in evaluating the performance of organic wastes is the exposure rate of available organic carbon, and it has been previously reported that the combined use of cellulosic materials can lead to comparatively higher performance in AMD treatment in long-term operation (Zagury et al., 2008).

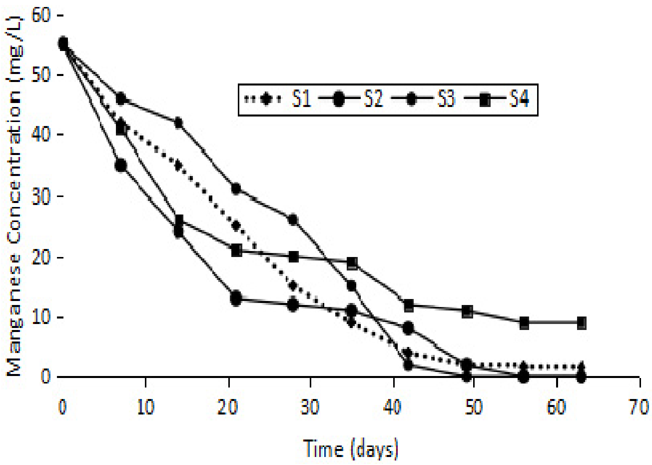
3.4 Effects of Contact Time in Metal Removal in Batch Reactors

The results for heavy metal reduction with time is presented in the Figure 3a, b, c and d. In the reactor (S4) the reduction was high from day10 to day 56 as compared to other reactors. However, the results indicated very poor trend in reactors S3 as shown in Figure 3a from day 10. Most of the reactors in Figure 3a shown very reluctant reduction from day 49 onwards. The trend in Figure 3a and 3c, the reduction of zinc in reactor (S3) was very low compared to other reactors. But highest removal efficiency of zinc was shown in the reactor (S4) (Figure 3c). The trend is quite different in the removal of manganese in reactor S4 shown the lowest compared to other reactors. Also, reactor S3 which contain mixed organic wastes has shown to be highest in manganese removal (Figure 3b and 3d). The reduction of zinc in S3 was low this is also supported by Amjmal et al., (1998) reported a similar trend of low performance in sawdust for the removal of copper. These results could be caused by the nature, type and chemical composition of the *Eucalyptus* spp. Other researchers (Adamczyk-Szabel et al., 2015; Fernize et al., 2017) reported that desorption of metals by plants and the level of pH in mine drainage can influence metal solubility and sorption. The foregoing observation is in line with this study results whereby reactor S3 that contained sawdust showed low pH (4.8), which would have been expected to affect the removal performance.

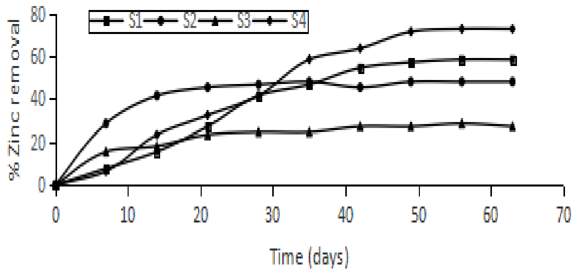
(a)



(b)



(c)



(d)

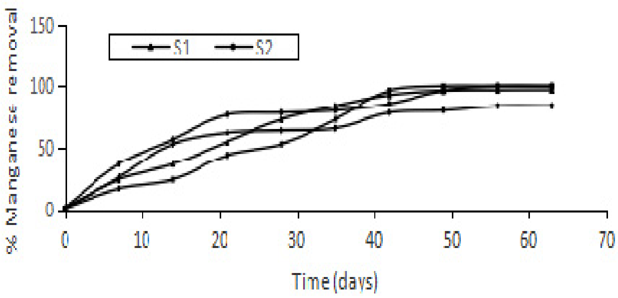


Figure 3. Variation of (a) Zn (b) Mn concentration and (c) Zn (d) removal efficiency in batch reactors for AMD treatment

It was shown that despite its high concentration (Table 1), manganese is significantly reduced (Table 3 and Table 4) in the reactors (S1, S2 and S3), but its removal was low in S4 (mixture of S1, S2 and S3) compared to other single reactors. This could be because manganese requires a highly alkaline condition to precipitate. Younger et al. (2002) suggested that metals such as manganese precipitate in environments with a strong alkaline condition and high pH. In this study, it was found that the reduction of metals in these reactors is likely dependent on the level of organic contents in organic wastes, which can increase the level of alkalinity during decomposition and degradation. Shabalala (2013) and Ludwig et al. (2002) have documented that the bacteria present in the reactors consume organic contents in the form of carbon under anaerobic conditions to produce carbonate, which increases alkalinity. This creates an environment where metals such as Mn, Cu, Fe and Ni dissolved in solution and precipitate. Furthermore, the manganese cycle, involving its three oxidation states (Mn(II), Mn(III), and Mn(IV)), plays a crucial role in both the soluble and particulate phases, significantly influencing the biogeochemistry of organic carbon, nutrients, and various trace elements (Jones et al., 2020). In the case of reactor S4, which contained both organic manure and sawdust, the presence of organic ligands in the solution may have maintained manganese in its dissolved form, even at elevated pH levels. This complexation can reduce the effectiveness of Mn precipitation and thus impact both its availability and mobility within the system (Nogueira et al., 2007; Khoshru et al., 2023).

In addition, the reactor with mixed organic wastes performed comparatively better in terms of heavy metal removal. This observation is supported by Waybrant et al. (1998) and Zagury et al. (2006) who found that a mixture of different organic wastes could improve performance better than using a single carbon source. The effects of increased performance in mixed organic substrates was due to the increase in nutrients resulting from a combination of different sources (Abou-Hussein et al., 2002). Likewise, Waybrant et al. (1998) also reported that the reactors with low organic content showed the lowest performance, while other reactors with high proportion of multiple organic content (mixture of several organic materials) showed the highest performance.

Therefore, the best approach to selecting the biological treatment option for AMD is to select appropriate organic wastes as electron donors for sulfate reduction, which in turn depends on the biodegradability of the organic wastes (Gibert et al., 2004). In general, this study found that using a mixture of organic wastes in bioreactors offers great potential to reduce sulfate, increase pH, and thereby control metal mobility.

4. Conclusion

This study observed a significant improvement in using organic wastes to treat AMD. The quality of the AMD water after 63 days of treatment showed a significant improvement of pH in reactor S1, S2 and S4 with >7.2, while the pH in reactor S3, which contains sawdust, improved the least. In general, this study showed that the highest sulphate reduction performance in the reactors occurs when mixed with other organic waste with results from 2277 mg/L to 108 mg/L (95%) and significant removal of manganese in all type of selected organic waste. Therefore, this study showed that the biological treatment of using selected organic waste is a promising technology to improve the treatment of AMD water.

Acknowledgments

Sincere gratitude is extended to North Mara Gold Mine for providing the initial financing for this study. Additionally, I would like to thank Dr. Stephen Mbuligwe and Prof. Gabriel Kassenga for their attentive supervision during preparation of this article. Last but not least, acknowledge the permission of the school of engineering and environmental studies at Ardhi University for the provision of space for laboratory activities.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal and publisher adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

Open access

Copyrights

References

Abou-Hussein, S. D., El-Shorbagy, T., & Abou-Hadid, A. F. (2002, April). Effect of cattle and chicken manure with or without mineral fertilizers on tuber quality and yield of potato crops. In *International Symposium on The Horizons of Using Organic Matter and Substrates in Horticulture 608* (pp. 95-100). https://doi.org/10.17660/ActaHortic.2003.608.12

Adamczyk-Szabela, D., Markiewicz, J., & Wolf, W. M. (2015). Heavy metal uptake by herbs. IV. Influence of soil pH on the content of heavy metals in Valeriana officinal is L. *Water, Air, & Soil Pollution, 226*, 1-8. https://doi.org/10.1007/s11270-015-2360-3

Amos, P. W., & Younger, P. L. (2003). Substrate characterisation for a subsurface reactive barrier to treat colliery spoil leachate. *Water Research, 37*(1), 108-120. https://doi.org/10.1016/S0043-1354(02)00159-8

ASTM. (2001). Standard test method for accelerated weathering of solid materials using a modified humidity cell. In American Society for Testing and Materials (p. 13).

Dikinya, O., & Mufwanzala, N. (2010). Chicken manure-enhanced soil fertility and productivity: Effects of application rates. Journal of soil science and environmental management, 1(3), 46-54. http://hdl.handle.net/10311/1003

Dube, V., Phiri, Z., Kuvarega, A. T., Mamba, B. B., & de Kock, L. A. (2024). Exploring acid mine drainage treatment through adsorption: a bibliometric analysis. *Environmental Science and Pollution Research, 31*(50), 59659-59680. https://doi.org/10.1007/s11356-024-35047-2

Elouear, Z., Bouhamed, F., Boujelben, N., & Bouzid, J. (2016). Application of sheep manure and potassium fertilizer to contaminated soil and its effect on zinc, cadmium and lead accumulation by alfalfa plants. *Sustainable Environment Research, 26*(3), 131-135. https://doi.org/10.1016/j.serj.2016.04.004

Ferniza-García, F., Amaya-Chávez, A., Roa-Morales, G., & Barrera-Díaz, C. E. (2017). Removal of Pb, Cu, Cd, and Zn Present in Aqueous Solution Using Coupled Electrocoagulation-Phytoremediation Treatment. *International Journal of Electrochemistry, 2017*(1), 7681451. https://doi.org/10.1155/2017/7681451

Gaikwad, R. W., & Gupta, D. V. (2008). Review on removal of heavy metals from acid mine drainage.

Gibert, O., De Pablo, J., Cortina, J. L., & Ayora, C. (2004). Chemical characterisation of natural organic substrates for biological mitigation of acid mine drainage. *Water Research, 38*(19), 4186-4196.https://doi.org/10.1016/j.watres.2004.06.023

Johnson, D. B. (2003). Chemical and microbiological characteristics of mineral spoils and drainage waters at abandoned coal and metal mines. *Water, Air and Soil Pollution: Focus, 3*, 47-66. https://doi.org/10.1023/A:1022107520836

Johnson, D. B., & Hallberg, K. B. (2005). Biogeochemistry of the compost bioreactor components of a composite acid mine drainage passive remediation system. *Science of the Total Environment, 338*(1-2), 81-93.https://doi.org/10.1016/j.scitotenv.2004.09.008

Jones, M. R., Luther III, G. W., & Tebo, B. M. (2020). Distribution and concentration of soluble manganese (II), soluble reactive Mn (III)-L, and particulate MnO2 in the Northwest Atlantic Ocean. *Marine Chemistry, 226*, 103858. https://doi.org/10.1016/j.marchem.2020.103858

Khoshru, B., Mitra, D., Nosratabad, A. F., Reyhanitabar, A., Mandal, L., Farda, B., ... & Das, P. K. (2023). Enhancing manganese availability for plants through microbial potential: A sustainable approach for improving soil health and food security. *Bacteria, 2*(3), 129-141. https://doi.org/10.3390/bacteria2030010

Kolmert, Å., & Johnson, D. B. (2001). Remediation of acidic waste waters using immobilised, acidophilic sulfate‐reducing bacteria. Journal of Chemical Technology & Biotechnology: International Research in Process. *Environmental & Clean Technology, 76*(8), 836-843. https://doi.org/10.1002/jctb.453

Kuyucak, N., Chabot, F., & Martschuk, J. (2006). Successful implementation and operation of a passive treatment system in an extremely cold climate, northern Quebec, Canada. In *Proceedings of the 7th International Conference on Acid Rock Drainage* (ICARD) (Vol. 38, pp. 3131-8). Lexington: American Society of Mining and Reclamation (ASMR).

Lewis, M. E., & Clark, M. L. (1997). How does streamflow affect metals in the upper Arkansas River. US Department of the Interior, US Geological Survey.

Loper, S., Shober, A. L., Wiese, C., Denny, G. C., Stanley, C. D., & Gilman, E. F. (2010). Organic soil amendment and tillage affect soil quality and plant performance in simulated residential landscapes. *Hort Science, 45*(10), 1522-1528. https://doi.org/10.21273/HORTSCI.45.10.1522

Ludwig, R. D., McGregor, R. G., Blowes, D. W., Benner, S. G., & Mountjoy, K. (2002). A permeable reactive barrier for treatment of heavy metals. *Groundwater, 40*(1), 59-66.https://doi.org/10.1111/j.1745-6584.2002.tb02491.x

McCarthy, T. S. (2011). The impact of acid mine drainage in South Africa. *South African Journal of Science, 107*(5), 1-7.https://hdl.handle.net/10520/EJC97144

Munawar, A., & Riwandi, R. (2010). Chemical characteristics of organic wastes and their potential use for acid mine drainage remediation. *Journal Nature Indonesia, 12*(2), 167-172. http://dx.doi.org/10.31258/jni.12.02.%25p

Neculita, C. M., & Zagury, G. J. (2008). Biological treatment of highly contaminated acid mine drainage in batch reactors: long-term treatment and reactive mixture characterization. *Journal of Hazardous Materials, 157*(2-3), 358-366. https://doi.org/10.1016/j.jhazmat.2008.01.002

Neculita, C., Zagury, G. J., & Bussiere, B. (2007). Efficiency of three reactive mixtures of organic wastes for the treatment of highly contaminated acid mine drainage. In OttawaGeo2007: The Diamond Jubilee Conference (pp. 1530-1537).

Ngure, V., Davies, T., Kinuthia, G., Sitati, N., Shisia, S., & Oyoo-Okoth, E. (2014). Concentration levels of potentially harmful elements from gold mining in Lake Victoria Region, Kenya: Environmental and health implications. *Journal of Geochemical Exploration, 144*, 511-516. https://doi.org/10.1016/j.gexplo.2014.04.004

Nogueira, M. G., Pazos, M., Sanromán, M. A., & Cameselle, C. (2007). Improving on electrokinetic remediation in spiked Mn kaolinite by addition of complexing agents. *Electrochimica Acta, 52*(10), 3349-3354. https://doi.org/10.1016/j.electacta.2006.03.115

Othman, A., Sulaiman, A., & Sulaiman, S. K. (2015). The study on the effectiveness of organic material in acid mine drainage treatment. *Jurnal Teknologi (Sciences & Engineering), 77*(2). https://doi.org/10.11113/jt.v77.5991

Quicasán, D. F., Forero, N. F., & Vasquez, O. Y. (2017). Acid mine drainage prevention using mushroom compost as organic amendment. *Revista Colombiana de Biotecnología, 19*(1), 92. https://doi.org/10.15446/rev.colomb.biote.v19n1.58904

Scharenbroch, B. C. (2009). A meta-analysis of studies published in Arboriculture & Urban Forestry relating to organic materials and impacts on soil, tree, and environmental properties. *Arboriculture & Urban Forestry (AUF), 35*(5), 221-231.

Shabalala, A. N. (2013). Assessment of locally available reactive materials for use in permeable reactive barriers (PRBs) in remediating acid mine drainage. *Water SA, 39*(2), 251-256. https://doi.org/10.4314/wsa.v39i2.8

Waybrant, K. R., Blowes, D. W., & Ptacek, C. J. (1998). Selection of reactive mixtures for use in permeable reactive walls for treatment of mine drainage. *Environmental Science & Technology, 32*(13), 1972-1979. https://doi.org/10.1021/es9703335

Younger, P. L., Banwart, S. A., Hedin, R. S., Younger, P. L., Banwart, S. A., & Hedin, R. S.

(2002). *Mine water hydrology* (pp. 127-270). Springer Netherlands.

Zagury, G. J., Kulnieks, V. I., & Neculita, C. M. (2006). Characterization and reactivity assessment of organic substrates for sulphate-reducing bacteria in acid mine drainage treatment. *Chemosphere, 64*(6), 944-954. https://doi.org/10.1016/j.chemosphere.2006.01.001

Zagury, G. J., Neculita, C., & Bussiere, B. (2007). Passive treatment of acid mine drainage in bioreactors: short review, applications, and research needs. Ottawa Geo2007, 14439-14446.