EVALUATION OF WETLAND PLANTS TREATMENT POTENTIALS FOR ACID MINE DRAINAGE IN TANZANIA

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Abstract

Acid mine drainage occurs when sulfide minerals in mining activities come into contact with water and air, generating water with a low pH, high levels of sulfate, and metals. Treating acid mine drainage is a major challenge in gold mining operations worldwide and can be very costly. This study aims to screen and experimentally test potential local wetland plants for acid mine drainage treatment. Selected wetland plants were tested in a 12-liter plastic container, simulating a wetland treatment. The results of this study revealed that four out of six plants survived under acid mine drainage conditions. These plants included Cyperus imbricatus, Pennisetum purpureum, Typha latifolia, and Phragmites mauritianus,which all showed survival over the 63 days of experimental monitoring. The remaining two plants, Ipomea aquatica and water lotus (Nymphaeaceae), died within seven days of the experiment. The surviving plants were able to increase the pH from 3.2 to 7.1 and lower the levels of sulfate and metals in the acid mine drainage water. Furthermore, these four plants were able to improve the water quality by more than 94%, reducing heavy metal levels significantly (Mn from 53 to 1 mg/L, Ni from 2.4 to 0.3 mg/L, and Fe from 2.3 to 0.03 mg/L). This study suggests that selected local wetland plants have the potential to be a sustainable technology for treating acid mine drainage water.

1.0 INTRODUCTION

Mining activities are considered the main source of contamination due to the release of pollutants, such as Acid Mine Drainage (AMD). This represents one of the most significant environmental problems in mining operations worldwide. AMD is the result of ongoing activities in mining operations around the world and has proven to be a significant environmental threat [1]. In the study by [2], researchers investigated the trends of AMD from 1991 to 2021. The results of their study demonstrated that AMD has consistently grown over the years, with a particularly high number of publications starting in 2014.The mineral responsible for the AMD process is pyrite [3]. When pyrite comes into contact with water and air, it can discharge or release acidic mine water containing elevated levels of metals that can have a detrimental impact on the surrounding environment and water quality [4].

There are many potential treatment technologies for AMD, but most of them are too expensive and require close monitoring, high energy consumption, and the generation of highly concentrated brine streams [5]. To overcome these treatment challenges and provide

a cheap and environmentally friendly solution, phytoremediation using wetland plants can be used to treat AMD water [6]. This method is a sustainable and inexpensive remediation strategy for removing pollutants, such as heavy metals, from AMD [7]. Plants can be incredibly useful in treating AMD, particularly when considering the use of metal-tolerant plant species to immobilize heavy metals. This is achieved through absorption and accumulation by roots, as well as precipitation in the rhizosphere [8]. Some plant species are able to thrive in harsh conditions. However, excessive concentrations of heavy metals can lead to oxidative stress and stomatal resistance in plants [9] and [10].

To combat this, plants have two main mechanisms for tolerating high levels of heavy metals in the soil [11]. The first is known as the accumulation strategy, where plants can accumulate metals in both high and low concentrations [12]. Different plants use different methods to treat contaminated water. Depending on the type of contaminants, various mechanisms may be employed by plants, such as rhizofiltration, phytodegradation, or rhizodegradation [13]. Additional studies [14] and [15] have also reported that phytoextraction, phytovolatilization, and rhizofiltration are effective ways for plants to remove pollutants from water. Wetland plant systems are more effective when aided by microorganisms like sulphate-reducing bacteria (SRB), which can convert sulphate to sulphide and eventually precipitate metals in the form of metal sulphides under anaerobic conditions. This process also increases alkalinity [16] and [17].

In general, the use of plants, especially wetland plants, is cost-effective and applicable to solve the problem of Acid Mine Drainage (AMD) through chemical and physical methods [18]. However, there is limited information on the use of this method to treat AMD, particularly in developing countries like Tanzania. Most studies have primarily focused on domestic wastewater treatment and have only considered common pollutants [19] [20]. Similarly, the majority of studies conducted worldwide have not utilized plants from tropical regions for treatment of AMD [21] [22] [23]. Furthermore, many researchers in Tanzania have published studies on using wetland plants, but these studies have not been screened based on environmental conditions, and the chosen plant

species have primarily focused on metal removal in contaminated soils [24], [25]. As a result, there is a lack of research assessing the potential of wetland plants for AMD water treatment. However, many active and passive AMD treatment methods are not environmentally friendly, not suitable for long-term management, and are expensive [26]. Therefore, this study aims to screen and experimentally test the potential of wetland plants to remove acidity, reduce sulfate concentrations, and decrease heavy metal levels in AMD water over time.

2.0 MATERIALS AND METHODS
2.1 Initial Screening of the Selected Plant Species Suitable for Treating Acid Mine Drainage
About forty (40) plants were screened in phase one (Table 1), based on a literature review of plants previously used as technology for other wastewater treatments, consultations with experts, and physical observations in the field. Some of these plants were found growing in the mining area. During the screening phase, plants were evaluated based on their suitability and relevance for treatment of AMD according to the following criteria as described by [27]: Potential to treat AMD, Uptake of heavy metals, Toxicity resistance, Ability to grow in aquatic environment, Ability to grow in low pH, Ability to grow in low nutrient, Ability to grow in terrestial environment, Ability to grow in subaquatic environment, Growth rate, Regeneration, Extensive root system, Easy of harvest, Evidence of application, Availability and Ability to grow in Tropical climates.

Each criterion was assigned weight points of 2-5 based on its importance, and a maximum score of 5 was given to plants with very high potential. The assessment was categorized based on the following levels[score assessment] as described by [28]: Very high, High, Medium, Low, Very low, and Extremely low, with scores ranging from 5 to 0, respectively. Equation 1 shows the formula used to calculate the overall score for each plant based on the screening criteria.

$$S_v = \sum S_c \ x \ W_c \qquad (1)$$

Where, S_v = Overall score of plant species, S_c = Score of plant species in an individual criterion, W_c = Weight of screening criteria.

Table 1: Plants subjected to initial screening for selected suitable plants for potentially treatment of acid mine drainage

Common name	Scientific name	Common name	Scientific name
Water hycinith	*Eichhornia crassipes*	Fragrant flatsedge	*Cyperus odoratus*
Water lettuce	*pistia*	Nut grass	*Cyperus rotundus*

Common name	Scientific name	Common name	Scientific name
Duck weed	*Lemina perpusilla*	Shingle flatsedge	*Cyperus imbricatus*
Mosquito fern	*Azolla*	Water fern	*Azolla*
Lotus	*Nymphaeaceae*	Arrowhead	*Sagittaria sagittaria*
Duck weed	*Lemina gibba*	Powdery alligator	*Thalia dealbata*
Water snowflake	*Nymphoides*	Blue pickerel weed	*Pontederia cordata*
Giant duck weed	*Myriphyllum*	Parrot's feather	*Myriophyllum aquaticum*
Water meal	*Wolfia spp*	Pitcher	*Sarracenia spp*
Water clover	*Marsilea mutica*	Green weed	*Enteromorpha sp*
Broadleaf cattail	*Typha latifolia*	Blue marsh violet	*Viola cucullata*
Southern cattil	*Typha domingensis*	Skunk cabbage	*Lysichiton americans*
Vertiver	*Vertiveria zizaniodes*	Pond weed	*Potomegeton sp*
Napier grass	*Pennisetum purpureum*	Bamboo	*Bambusoideae*
Narrowleaf cattail	*Typha angustifoila*	Spikes edges	*Kyllinga erectus*
Cattail	*Typha capensi*	Caster bean	*Ricinus communis*
Common reed	*Phragmites australis*	Eucalypts	*Eucalyptus*
Acute reed	*Phragmites mauritianus*	Mimosa	*Mimosa pigra*
Papyrus sedge	*Cyperus papyrus*	Giant reed	*Arundodonax*
Water spinach	*Ipomoea aquatica*	Drumstick tree	*Moringa Oleifera*
Fragrant flatsedge	*Cyperus odoratus*		
Nut grass	*Cyperus rotundus*		
Shingle flatsedge	*Cyperus imbricatus*		
Water fern	*Azolla*		
Arrowhead	*Sagittaria sagittaria*		

2.2 Preparation and Planting of Six Selected Plants

The following plants were collected (*Cyperus imbricatus*, *Ipomea aquatica*, *Pennisetum purpureum*, *Typha latifolia*, *Phragmites mauritianus*, and Water *lotus*) and transported directly to the experimental hall at the Ardhi University, where they were transplanted to plastic containers. The plastic containers contained a mixture of sand and fresh AMD. All of the plants were grown in the same environmental conditions throughout the period of study. For this study, sand was collected within the experimental hall and thoroughly washed with tap and deionized water to remove any foreign particles. It was then sterilized. In a study by [29], it was reported that the sand used in the experiment was thoroughly washed several times using tap water and distilled water. Other studies [30] also reported that all plants and materials used were washed with water to remove any suspended matter.

Additionally, in a study by [31] on biosand filters, it was reported that the sand was washed with distilled water and left to dry in the sun before being used. The sand was used as a substrate for the plants, providing a growing medium and support for biochemical and chemical transformations. The sand did not require any additional suspended particles to interfere with the experiment, as the purpose was solely to evaluate the potential of wetland plants for treatment of AMD. In a study by [32], it was suggested that sand only needs to support the plants for pollutant removal and proper water movement.

2.3 Experimental Design for Acid Mine Drainage Treatment with Selected Plants

Phase one of this study involved the selection of wetland plants based on their ability to treat acid mine drainage (AMD). A total of six plants were selected for this experiment: C*yperus imbricatus, Ipomea aquatica, Pennisetum purpureum, Typha latifolia, Phragmites mauritianus*, and Water *lotus*. These plants were selected based on their scores in Table 1. The aim of this phase was to design the experiment setup and monitor treatment performance. Throughout this experiment, distilled water was added daily to compensate for water loss through plants' transpiration and evaporation. The fresh AMD (Table 2) used in this experiment was collected from the potential acid-forming waste rock dump leaching pond at the North Mara Gold Mine, located at [1° 28.416'S and 34° 30.992'E].

Batch experiments were set up using a plastic container of 12 L to plant the selected plants. All six plants were planted in separate containers with sand and fresh AMD. In order to determine the plants' efficiency in removing pollutants, an additional container with only sand and AMD was also set up as a control. The experiment, designed by [33], considered the planting of the selected wetland plants as a single factor. This involved seven treatments with three replicates each, resulting in 21 experimental units. The experimental treatments included planting with C. imbricatus, I. aquatica, P. purpureum, T. latifolia, P. mauritianus, and water lotus, while another container was used as a control with only sand and AMD, without any plants.

Table 2: Characteristics of actual AMD used for experimental testing

Parameter	Acid Mine Drainage
pH	3.1
Ec (µs/cm)	2950
Sulphate (mg/L)	2277
Copper (mg/L)	0.49

Iron (mg/L)	2.3
Manganese (mg/L)	55
Nickel (mg/L)	2.5
Zinc (mg/L)	7.7

2.4   Water Sampling and Analysis

Water samples were collected from the experimental setup and sent to the environmental engineering laboratory at Ardhi University for laboratory analysis. The analysis focused on physical and chemical parameters, specifically heavy metals. The experiment lasted for 63 days. This is because plants need to be fully acclimated to maximize their potential for removing pollutants, as suggested by [34]. The pH and electrical conductivity were measured using the potential metric method with Sension 378. The heavy metals nickel, zinc, and copper were analyzed with AAnalyst 100 and a PerkinElmer Instrument (Atomic Absorption Spectrometer). Iron was analyzed using the 1-1-Phananthroline Method with a DR/4000U spectrophotometer. Aluminium and sulphate were both analyzed using the turbidimetric method with a DR/4000U spectrophotometer, following the standard method proposed by APHA (2012). Manganese was analyzed using the HACH product of the periodate oxidation method, also with a DR/4000U spectrophotometer. The selection of heavy metals was based on the characteristics of actual AMD (Table 2).

2.5   Data Analysis

Selected wetland plants (Cyperus imbricatus, Phragmites mauritianus, Phragmites purpureum, and Typha latifolia) were chosen for their effectiveness in treating acid mine drainage. The mean (x) ± standard deviation (SD) of their removal efficiency was calculated. A one-way analysis of variance (ANOVA) was performed on the selected plants, with a significance level of $p < 0.05$ to determine statistical significance. The removal efficiency was calculated as a percentage in Microsoft Excel [35].

3.0   RESULTS AND DISCUSSION

3.1   Screened Potential and Suitable Plants for Acid Mine Drainage Treatment

The results of screening plants species suitable for treating AMD presented in Table 3. The screening process considered factors such as heavy metal uptake, availability potential to treat AMD, toxicity resistance, and growth rate. The study also reviewed the literature on these plants to determine their potential to treat AMD. After considering all the factors, six plant species were selected as suitable for treating AMD. The plants were ranked based on their performance in the screening process, with *Typha latifolia* being the top performer, followed by *Cyperus imbricatus, Pennisetum purpureum, Phragmites*

mauritianus, Ipomea aquatica, and *Nymphaeaceae*. The study also took into account the potential availability of these plants for treating AMD within or near mining sites. If a plant was not potentially available, it was given a low score and disqualified from the selection process. The same was done for heavy metal uptake, toxicity resistance, and growth rate. In summary, this study identified six plant species that have the potential to treat AMD, with *Typha latifolia* being the most suitable. The results of the initial screening provide a useful guide for future research in the field of AMD treatment.

Table 3: Selected plant species based on initial screening criteria for experimental testing

Common name	Scientific name	Score
Water Lotus	*Nymphaeaceae*	187
Water spinach	*Ipomoea aquatic*	232
Napie grass	*Pennisetum purpureum*	263
Broadleaf cattail	*Typha latifolia*	266
Acute reed	*Phragmites mauritianus*	255
Shingle flatsedge	*Cyperus imbricatus*	265

Based on the criteria set for identifying potential plants for treating AMD (Table 3), T*ypha latifolia* scored the highest during the initial screening and was selected as the most suitable candidate. A study conducted by [36] found that *Typha latifolia* is a rapid colonizer commonly found in wetlands in Tanzania, the USA, and globally. Additionally, [37] noted that *Typha catt*ail roots provide a matrix for physically retaining metal sulfides. In another study, [38] identified *Cyperus grandis, Phragmites mauritianus,* and *Typha spp* (*domengesis* and *capensis*) as viable options for removing nitrogen from domestic wastewater, and these plants have been successfully implemented in countries such as Colombia, Brazil, India, Kenya, and Uganda.

The results of the plant screening (Table 3) suggest that Water lotus ranks lower than other species because it thrives better in domestic wastewater than in AMD, and it requires more nutrients to grow. This is supported by [39], who used lotus plants for domestic wastewater treatment and found that they outperformed other plants. Therefore, it is not recommended to use Water lotus for treating AMD. Based on this, it can be concluded that *Ipomea aquatica, Pennisetum purpureum, Typha latifolia, Phragmites mauritianus*, and *Cyperus imbricatus* are the most suitable plants for treating AMD.

3.2   Acid Mine Drainage Water Treatment Performance in the Selected Plant Species

The evaluation of the AMD treatment performance of selected plants is presented in Table 4, Figure 1, and Figure 2. These plants had scored higher during the

initial screening (Table 3) based on the screening criteria. They were then subjected to a batch experiment that lasted for 63 days. The results from the experimental performance tests are presented in Table 4. The selected plants were *Cyperus imbricatus, Phragmites mauritianus, Pennisetum purpureum*, and *Typha latifolia*. All plants were able to sustain AMD and raised the pH from 3.1 to 7.4. However, *Typha latifolia* was the lowest performer in terms of the removal of zinc and copper. However, the ANOVA test indicated that there were no significant differences among these four plants, with P>0.05.

This study revealed that all plants were able to reduce heavy metal concentrations (Table 4). Additionally, *Cyperus imbricatus* was able to significantly decrease the sulphate level in the AMD from 2277 mg/L to 28 mg/L by the end of the experiment, showing an impressive 98.8% removal efficiency. The remaining plant species also showed promising results with *Phragmites mauritianurs* removing up to 393 mg/L (83%), Pennisetum purpureum removing 126 mg/L (95%), and *Typha latifolia* removing 502 mg/L (78%). Furthermore, remarkable reductions in manganese

were observed with *Cyperus imbricatus* (97%), *Phragmites mauritianus* (97%), *Pennisetum purpureum* (99%), and *Typha latifolia* (94%). The selected plant species also demonstrated significant decreases in iron levels, with *Cyperus imbricatus* (99%), *Phragmites mauritianus* (99%), *Pennisetum purpureum* (98%), and *Typha latifolia* (98%) all having high removal efficiencies.

The results of this study showed that all three wetland plants were effective in removing heavy metals (Mn, Ni, and Fe) from AMD water, with a removal efficiency of >94% for all selected plants. This demonstrates the significant impact of plants on improving the quality of AMD water (Table 4). In comparison, the control sample, which was not exposed to any wetland plants, showed no discernible changes in the initial AMD water quality (Table 2). Additionally, statistical analysis revealed a significant difference (P<0.05) between the control and wetland plants after 63 days of treatment, highlighting the effectiveness of wetland plants in removing heavy metals from AMD water.

Table 4: Wetland plants performance results of the selected wetland plant species for treatment of acid mine drainage after 63 days of batch experiment (x ± SD, n = 9)

| Parameter	Control	*Cyperus Imbricatus*	*Phragmites mauritianus*	*Pennisetum purpureum*	*Typha Latifolia*
pH	3.2	7.4± 1	7.1± 1.3	7.1± 0.9	6.9± 0.9
EC (µS/cm)	2900	449± 609	1913± 76	946± 488	950± 482
SO_4^{2-} (mg/L)	2276	28 ± 646	393 ± 625	126 ± 664	502 ± 566
Mn (mg/L)	53	0.2± 12	0.2± 11	0.1± 9	3.5 ± 14
Zn (mg/L)	7.5	3.2 ± 0.8	3 ± 1.2	2.2± 1.6	4.3 ± 0.4
Cu (mg/L)	0.45	0.01 ± 0.2	0.01 ± 0.1	0.03 ± 0.1	0.02 ± 0.2
Ni (mg/L)	2.4	0.01 ± 0.5	0.04 ± 0.8	0.01 ± 0.8	0.005 ± 0.8
Fe (mg/L)	2.3	0.03± 0.6	0.01 ± 0.6	0.04 ± 0.7	0.05 ± 0.5

(a)

(b)

(c)
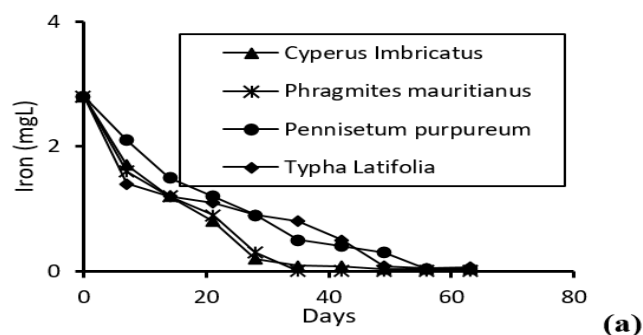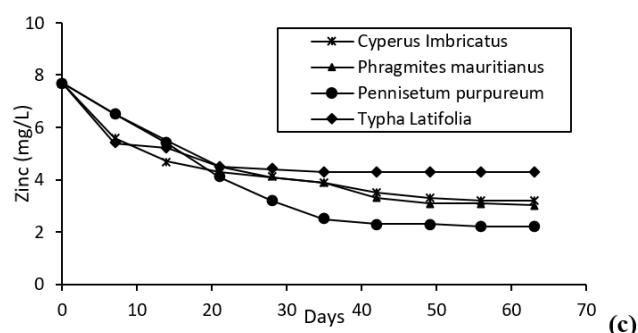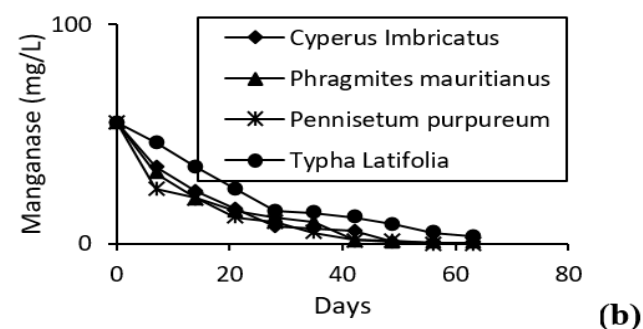
Figure 1: Heavy metal reduction (a) Iron (b) Manganese and (c) Zinc in selected wetland plants during treatment of acid mine drainage for 63 days

The heavy metal removal trend , pH improvement and sulphate reduction (Figure 1, 2 and 3) showed that significant removal occurred during the first 30 days of the experimental run, with the exception of zinc, which was not effectively removed. The performances for the selected plant species for zinc removal were as
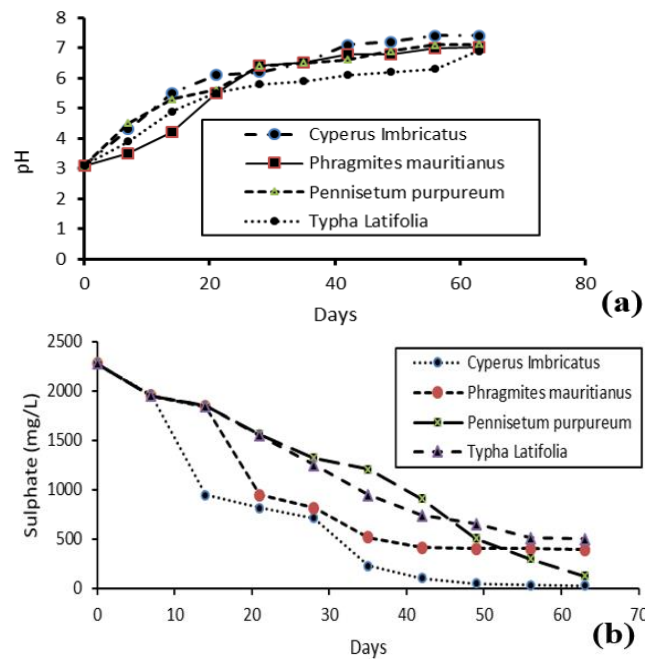
follows: *Cyperus imbricatus* (58%), *Phragmites mauritianus* (61%), *Pennisetum purpureum* (71%), and *Typha latifolia* (44%). This performance was very low compared to the removal rates for other metals. A study conducted in India by [40] observed a similar trend, with 61% zinc removal when combined with two plants, *Phragmites australia* and *Typha latifolia*. [41] also found a trend of Fe>Cu>Mn>Zn for heavy metal removal efficiency, with zinc removal being the lowest.
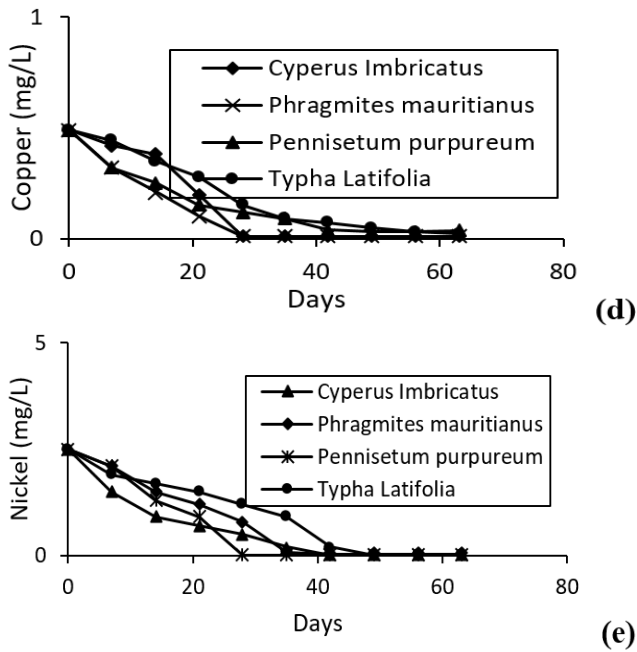
Figure 2: Heavy metals reduction (d) Copper and (e) Nickel in selected wetland plants during treatment of acid mine drainage for 63 days

This study aimed to analyze the mechanism of metal removal during the experimental run, particularly focusing on the contribution of each plant species. It was found that microbial attachments to the root zone played a significant role in accelerating the removal process, specifically through the presence of sulphate reducing bacteria (SRB). These bacteria helped reduce the levels of sulphate in the acidic mine drainage (AMD) water by converting it into sulphide. The formed sulphide then combined with dissolved metals to form a complex compound under high pH levels. Furthermore, the anaerobic conditions within the root zone of plants promoted the production of organic matter through the decomposition of dead plant material. This, in turn, increased the levels of bicarbonate and resulted in an increase in alkalinity and pH levels in the AMD water. Similar observations were made by [42], who also noted that SRB can raise the pH and alkalinity of AMD water and immobilize dissolved metals through the formation of metal

sulphides when an organic carbon source is present within wetland plants.

Figure 3: pH improvement (a) and Sulphate reduction (b) in selected wetland plants during treatment of acid mine drainage for 63 days

The high reduction of manganese in *Cyperus imbricatus, Phragmites mauritianus*, and *Pennisetum purpureum* might be associated with an increase in the pH level of AMD water and the extensive root zones of these plants, which facilitate accelerated adsorption and higher sorption area for metals. According to [43], certain plant species have a strong metal sorption capacity. Additionally, [44] showed that wetland plants like *Cyperus spp* are effective in phytoremediation of copper, manganese, and zinc. [45] also mentioned that the expansive rhizosphere of plants provides an enriched area for microbes to play a role in the degradation of pollutants. Furthermore, [46] and [47] reported that the rhizosphere of plants promotes the growth of microorganisms that are essential for heavy-metal immobilization and uptake by plants.Researchers [48] and [49] have reported that heavy metals are removed from plants through a combination of settling, sorption, co-precipitation, microbial activity, and plant uptake. Additionally, [50] has found that manganese can form insoluble compounds through oxidation-reduction processes, which often occur in wetland plants and result in the formation of oxides. Other ways in which plants contribute to metal removal include precipitation and co-precipitation. For example, Fe oxides can co-precipitate copper, nickel, zinc, and manganese, while manganese oxides can do the same for iron, nickel, and zinc [51]. In addition to this, it has been found that

Cyperus imbricatus is particularly effective in removing sulphates. This is due to the plant's extensive root system, which supports the growth of a large microbial population and enhances adsorption at the root zone. This is supported by a study by [52], which showed that using plants with suitable substrates can promote the growth of sulphate-reducing bacteria (SRB) in the anaerobic conditions of AMD treatment.

In AMD water, sulphates are abundant, and they are reduced by SRB to produce hydrogen sulphide. This gas then reacts with heavy metals, forming insoluble metal sulphides. In this particular study, *Cyperus imbricatus* and *Typha latifolia* were able to remove 58% and 44% of zinc, respectively. This aligns with the findings of [53], who observed that different plant species have varying abilities to remove metals. Furthermore, [54] noted that each plant has a specific capacity for removing different heavy metals.

Researchers [55] observed that zinc removal in wetland plants was the least effective compared to other metal. For instance, in a study by[56], it was found that there was a low removal of zinc in the remediation process, which could be attributed to the desorption process of zinc by plants. Similarly, other studies have also reported that the removal of zinc is influenced by the pH level in mine drainage [57] as it affects both the solubility and sorption of zinc. However, this study found that all selected plant species (*Cyperus imbricatus, Phragmites mauritianus, Pennisetum purpureum*, and *Typha latifolia*) showed the ability to remove significant amounts of Ni, Fe, and Mn from AMD water during experimental performance testing. Of these, the copper removal efficiency of *Typha latifolia* was lower than that of the other plants. [31] also reported that *Phragmites spp* removed more heavy metals than *Typha latifolia*. Additionally, [31] found that *Phragmites spp* showed higher accumulative capacities for heavy metal removal than *Typha latifolia.*

4.0 CONCLUSION
The objective of this study was to evaluate the potential of wetland plants for the treatment of acid mine drainage. The use of locally selected wetland plant species in acid mine drainage treatment has shown great performance due to its environmental sustainability. Based on the results of this study, four plants were able to raise the pH [55%] of acid mine drainage water to nearly neutral, as well as decrease levels of manganese [98 %], nickel [88%], and iron [98%]. Additionally, these plants were able to reduce sulphate levels by more than 78%, with the highest reduction achieved by *Cyperus imbricatus*. The suitability of these four selected plant species (*Phragmites mauritianus, Pennisetum purpureum, Typha latifolia, and Cyperus imbricatus*) demonstrates promising technology for the sustainable treatment of acid mine drainage in mining operations.

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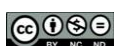
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