Water Hyacinth (*Eichornia crassipes*) as a Phytoremediation Agent for Heavy Metal Removal in Acid Mine Drainages Generated from the Urban Mining of e-Wastes: A Bibliometric Review

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Abstract
Generation of Acid Mine Drainage (AMD) is a problem that is associated with the urban mining of e-waste. Raised acidic conditions resulting from AMD discharge into the surrounding environments and cause toxic heavy metals (HMs) to dissolve, transport, and accumulate in the aquatic environments. Since the elevating concentrations of heavy metals due to AMD discharge exceed the threshold limits, beyond which the health of the living organisms is compromised, remediation of AMD has proven to be taken into consideration. Out of many strategies, passive treatment techniques can be mentioned as the newest approach to remediation AMD. Remediation methods for AMD can be divided into two categories, and they are active systems and passive systems. When comparing these two methods, active systems accrue more financial costs than passive treatments. More than 50 studies have focused on constructed wetland systems under passive technologies since it is self-sustaining once established, and they are cheaper than active treatment systems. The use of several aquatic plants such as water hyacinth, water lettuce, and water cabbage for the remediation process is of significance in constructed wetland systems. This study reviews the experimental findings on HM removal under several conditions using water hyacinth plants in different studies that have been done previously.

Keywords: Acid mine drainage, Heavy metal, Phytoremediation, Urban mining

1. Introduction

Recently the demand for natural resources has increased due to the rapid growth in the population, and there is less supply from conventional mining. Due to those industries are more focusing on the use of recycled materials. Therefore, industries move their focus to the use of recycled materials from e- wastes. As such, industries have explored novel techniques for the recycling process. Urban mining is such a recycling process. Though urban mining is a sustainable method, it has contributed to significant adverse environmental calamities in, and the major environmental impact associated with them is the generation of Acid Mine Drainage (AMD) [1]. AMD is metal-rich water formed from the chemical reaction between water and rocks containing sulfur-bearing minerals. The high acidity conditions in mine drainage resulted in the dissolution of HMs in the adjoining area. Elevating concentrations of heavy metals (HMs) give rise to a considerable threat to the environment, especially when the allowable threshold limits of various HMs which are harmful to living organisms are exceeded [1],[2]. Considering the damages that happen to the environment, several techniques such as pH modification, ion exchange, the addition of chemical and phytoremediation have been introduced for the remediation of these HMs. Among these techniques, phytoremediation plays an important role since it is a green technology.

According to Johnson and Hallberg (2005), oxidation of Iron Pyrite was the main primary cause of AMD generation. pH; temperature; oxygen content of the gas phase; oxygen concentration in the water phase; degree of saturation with water; surface area of exposed metal sulfide; chemical activation energy required to initiate acid generation; and bacterial activity are the primary factors cause for the AMD generation that has been stated by Akcil and Koldas (2006).

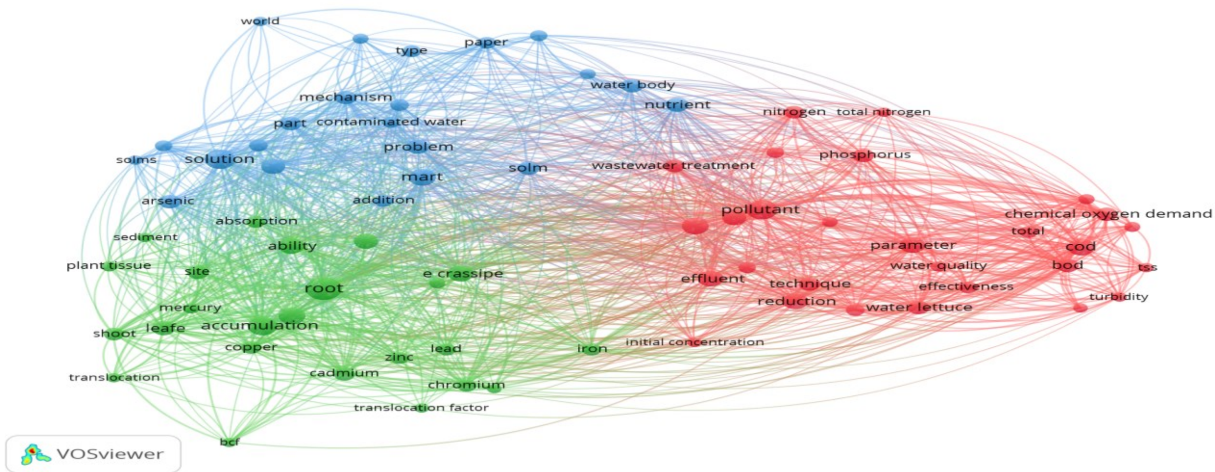

Figure 1: Text data map.

Several authors have also shown that other metal sulfide minerals also produce AMD rather than iron sulfides. Mainly metal contamination associated with this AMD depends on the type and amount of sulfide mineral oxidized, as well as the type of gangue minerals present in the rock. Mainly HMs like Fe, Cu, Cd, Zn and As are present in the mine drainage [1],[3],[4].

A collection of 70 papers from a search in the Scopus database revealed the past and present trends and opportunities. Figure 1 shows the most cited text among these selected research papers related to the plant part considering the heavy metal accumulation. In each network, it shows how the relevant texts are related to the others and from that, the most focused areas can be identified. Through the analysis of this network, plant roots as the remediation method and arsenic as the remediation HM were selected for the studies since they linked mostly with the relevant study. Though water hyacinth and other aquatic plants have the same importance in all studies, water hyacinth was selected due to its availability in Sri Lanka.

Previously many studies have been done to investigate the HM removal capacity by employing Floating Treatment Wetland (FTW) systems. As a phytoremediation media, *Eichornia crassipes* which is a common aquatic weed, is used for the HM remediation process since this plant has the capability of hyperaccumulation [5]. All the tests are carried out under different climatic situations and conditions such as adding of chelating agents. In this study all the results related to the HM removal capacity obtained from the previous studies have been analyzed to obtain knowledge on phytoremediation efficiency as a green technology method.

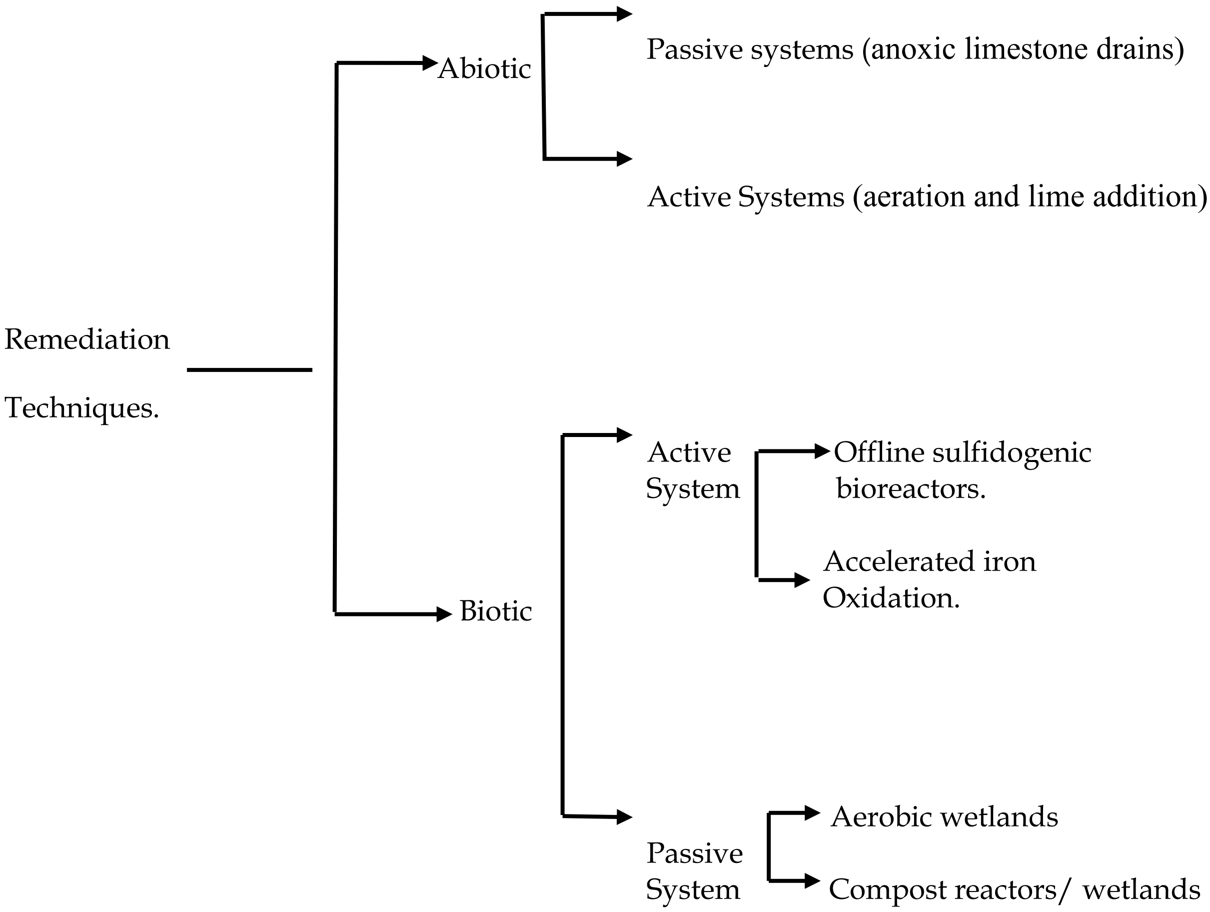

Figure 2: Remediation techniques of AMD.

2. Heavy metal remediation techniques

Removing metals and neutralizing acidity are the main aims of the treatment of contaminated water [6]. Remediation methods for AMD can be divided into two broad categories: active systems and passive systems. Active systems can be employed mainly for continuous operations [6]. Techniques to remediate AMD are shown in Figure 2.

pH modification, ion exchange, biology-based treatments, adsorption, electrochemical treatment, and physical process are the technologies involved in the active remediation system. Active treatment methods generally accrue more financial costs due to constant operation and maintenance than in passive systems [7]. Passive systems have an added advantage in HM remediation due to the self-sustaining ability of the passive system after its initial setup. Chemical passive treatment by adding chemicals such as limestone, polymers, or others and passive biological treatment represented by primarily constructed wetlands and secondary algal systems or special bioreactors are the treatment methods included in the passive systems [8].

Among passive treatment methods, wetlands have become a favourable option compared with the other treatment methods due to their self-sustaining ability after establishing the remediation process. They are cheaper than active treatment systems [7]. Also, the active treatment technologies require external energy to be supplied in the remediation process. The energy may be supplied physically or chemically to the system. The passive technologies utilize natural sources of energy like sunlight, gravity, chemical and biochemical reactions within the system.

2.1 Remediation method used in wetlands

Phytoremediation is the main remediation method employed in the constructed wetland systems. Phytoremediation has become a recognized pathway for contamination removal from polluted water bodies effectively, and this can mention as a solar-driven technique. Generally, passive techniques are useful for remediating contaminated aquatic environments by AMD over the last two decades [9]. Solidification, soil washing, and permeable barriers are the remediation techniques in constructed wetlands through phytoremediation are more favourable than the others because it is an alternative technique to high cost and high energy conventional method since phytoremediation is cost-effective. This method is considered as “Green insurrection” in the field of innovative clean-up technologies [10].

Due to the applicability even in the remote areas in all climatic zones where plants can have favourable growth and easier of its performance, phytoremediation techniques become more favourable in the remediating process.[11] Various phytoremediation mechanics are available, and they are as follows.

- Phytoextraction – Uptake mechanism of contaminants by plant roots and movement of the contaminants from the roots to aboveground parts of the plant [12]
- Rhizofiltration - adsorption or precipitation of contaminants that are in the solution surrounding the root zone onto plant roots due to biotic or abiotic processes [12]
- Phytostabilization - Immobilization of contaminant through absorption and accumulation by roots, adsorption onto roots or precipitation within the root shoot zone of plants is taken place [11]
- Rhizodegradation- Disintegration of an organic contaminant through a microbial activity that is enhanced by the presence of the root zone [13].
- Phytodegradation - Breakdown of contaminants taken up by plants through metabolic processes within the plant [6].
- Phytovolatization - Uptake and transpiration of a contaminant by a plant with the release of the contaminant or modified form of the contaminant to the atmosphere from the plant [12].

There are many limitations as well as advantages of the phytoremediation process. Time-consuming can be mentioned as one of the main limitations in this process. The rate of remediation under this method depends on the climatic condition, level of contamination, soil chemistry, age of the plant, root depth and contaminant concentration [9].

2.2 Plants for the phytoremediation process

The concept of using plant-based systems and microbiological processes to remediate AMD is used in phytoremediation. Therefore, in constructed wetlands, plants play a major role when remediating the contaminated water bodies. A series of critical physical, biological, and chemical processes within the constructed wetland wastewater treatment system [3]. Wetland plants stabilize the basin substrate, limit the channelized flow, and facilitate the settling of suspended matters by slowing down water velocities. Mainly carbon, nutrients, and trace elements are uptaken by the plant and incorporated into plant tissues. Further, plants transfer gases between the atmosphere and the sediments. Oxygenated microsites within the [14]. The selection of appropriate plant species to employ in constructed wetlands is important in achieving better performance from constructed wetlands. Tolerability of the selected plant to a saturated waterlogged substrate, high concentrations of wastewater loads, and biological traits of the plants such as fast growth rate, large biomass, and well-developed root system are identified as desirable features of plants that can be used in constructed wetlands. Local availability, aesthetic beauty, and the after-use values of the selected plant species are also equally important when selecting plant species used in the constructed wetlands [15]. Water hyacinth and water lettuce are the most common plants among the floating leaf that is being employed for wastewater treatments [16]. Mostly, the accumulation of heavy metals happens through the fibrous root design and the large biomass of these plants.

Figure 3: Water hyacinth.

Figure 4: Water Cabbage.

Figure 5: Water Lettuce.

3. Challenges in the phytoremediation process

The lengthy period for the clean-up, the slow growth rate of the plant and biomass handling after the remediation process can mention as the challenges in the remediation process.

Among these, one of the major problems in the phytoremediation process is to handle the biomass after the accumulation of heavy metals into the plants. If these biomasses are directly introduced into the environment without following proper disposal methods, accumulated heavy metals are again spreading. Van Ginneken et al. (2010) show that combustion of these heavy metal accumulated plants is the preferable method for dispose that can generate energy. Application of the bottom ash non-hazardous solid waste as construction aggregate or in fertilizer formulation in the case of essential trace metals can be mentioned as a revolutionary stage that determines the success of phytoremediation techniques [7].

4. Conclusion

Urban mining-related issues have increased, and the available studies in green remediation techniques have expanded in parallel. The applicability of the water hyacinth plant as a phytoremediation agent is important in the remediation process within the local environment. Nearly 70 studies have revealed the effectiveness of the phytoremediation process compared to the other available techniques. Commonly all the studies reveal that phytoremediation is an effective and cheap method for HM remediation since it promotes green technology. Mostly roots, stems, and leaves of water hyacinth plants can accumulate heavy metals effectively. Indirectly the green technologies such as phytoremediation provide the solution for the problems that cause by aquatic plants such as water hyacinth to the water bodies since these plants show invasive growth.

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