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Exploring potential phytoremediation in the terrestrial and aquatic mined area in the Philippines: An integrative review

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Ernil D. Sumayao*[1]
Biliran Province State University[1]
Naval, Biliran, Philippines
strikinglight23@gmail.com[1]

Jay P. Picardal[2]
Delsa Ariaso[3]

Cebu Normal University[23]
Cebu City, Philippines
picardalj@cnu.edu.ph[2]
abulenciadelsa@gmail.com[3]

Abstract
The mining of heavy metals is one of the activities in the Philippines that provide jobs and income to the country. However, improper disposal of these heavy metals resulted in soil and water pollution. While phytoremediation is a green strategy that uses hyper-accumulator plants and their rhizospheric microorganisms to stabilize, transfer, or degrade soil, water, and environmental pollutants. Thus, this paper focused on exploring potential phytoremediation in the Philippines' heavy metal polluted mined area. An integrative review was employed, and data were grouped based on their similarities and differences, described and thoroughly discussed. Based on the study's result, several plant species naturally grown in the area accumulated more heavy metals like copper, lead, nickel, mercury, and arsenic. Some plant species act as hyperaccumulators, phytostabilizers, and heavy metal tolerant. Moreover, these phytoremediators stored these heavy metals in their roots, rhizomes, and shoots. It is encouraged that the government includes phytoremediators' use in the rehabilitation of heavy metals polluted mined areas.

Keywords: *Environmental Chemistry, Environmental Management, Mining Industry, Soil and Water Pollution, Heavy Metals*

Introduction
Metallic minerals are abundant in numerous regions thanks to the Philippines' extensive natural resources. However, ecologically detrimental activities in the Philippines, including large-scale mining, have harmed Filipinos' health, lives, food security, livelihood, and way of life (Berame et al., 2020). During mining and post-mining, these activities and the minerals left in the area create pollution and affect the living organisms nearby. The mining industry is the mining, extracting, and collecting of essential non-metallic minerals, metal minerals, and energy resources (Stilwell et al., 2000; San Cristobal & Biezma, 2006; Ejdemo & Soderholm, 2011). Copper (Cu), lead (Pb), nickel (Ni), mercury (Hg), and arsenic (As) are some of the minerals that are mined all around the world. However, the use of the Earth's crust disrupts geological processes, primarily affecting the balance of the natural cycle of matter in the biosphere, leading to the introduction of substances and compounds

that are not specific to the terrestrial and aquatic ecosystem (Jabbarov, 2021).

In the Philippines, the government and private mineral industry mined metals like copper, nickel, lead, mercury, arsenic, chromium, gold, cobalt, iron, silver, and zinc, and these minerals are exported around the world (Fong-Sam, 2005). However, arsenic, lead, mercury, nickel, and copper cause toxicity to flora and fauna in soil ecosystems. Most of these metals are readily stocked in plants, enter the food chain, and get transferred to humans, which causes severe disorders and diseases (Awa & Hadibarata, 2020; Nedjimi, 2009). Additionally, Tabatabaei and Mohammadi (2013) found that increasing mining activities cause environmental problems. These different activities and the difference in the output wastes in this civil purification process to remove various pollutants are not fully realized. Industrial output, after a brief treatment, is directly poured into the soil or groundwaters. Daverey (2020) pointed out that humans have supplemented significant pollutants to the earth, water, and atmosphere biotopes due to industrial activities, such as mining ores, gas emission, pesticide application, and municipal waste production. Thus, proper treatment and remediating of this waste pose a challenge to the government, society, and scientists to protect and conserve the environment.

Plants may absorb ionic substances in the soil, even in low quantities, via their root system. Plants extend their root systems into the soil matrix and form rhizosphere ecosystems to absorb heavy metals and control their bioavailability, recovering damaged soil and regulating soil fertility (Ali et al., 2013; Jacob et al., 2018; DalCorso et al., 2019 as cited in Yan et al., 2020). Hence the need to use phytoremediation will produce beneficial results. Phytoremediation is a green strategy that uses hyper-accumulator plants and their rhizospheric microorganisms to stabilize, transfer or degrade pollutants in soil, water, and the environment (Liu et al., 2020). This technology is considered well-efficient, cheap, and adaptable to the environment (Ashraf et al., 2010). These species of plants used five types of phytoremediation applied: phytodegradation, phytofiltration, phytoextraction, phytostabilization, and phytovolatilization. On the other hand, several kinds of research and critical reviews were conducted by different researchers, like phytoremediation as green technology (Paz-Alberto & Sigua, 2013) and assessment of the seagrass as phytoremediation (Paz-Alberto et al., 2015), however, there are only limited reviews on potential plant species that will serve as phytoremediation in the Philippine setting. Thus, this integrative review was made to identify the commonly mined metals and their potential phytoremediation for rehabilitation of the polluted mined area in the Philippines. The study aimed to identify the common metals mined and likely plant species used as phytoremediation in the Philippines. It specifically sought to identify the common heavy metals collected in the mining industry and its potential plant species that can be used as phytoremediation in rehabilitating heavy metals polluted mined areas in the country.

Methodology

The study employed an integrative review to identify the common heavy metals in the Philippines mined area. Likewise, this design determines the potential phytoremediators that could mitigate the pollution in the affected area. An integrative review is a process of collecting and analyzing relevant research. The researcher utilized survey articles in the literature using the databases of Google Scholars, Elsevier, Taylor & Francis Online, and other Philippine Journals Indexed in Scopus that provide valid and reliable studies. Using Publish or Perish search engine, the researcher enters keywords like "phytoremediation", "bioremediation", "phytoremediation in the Philippines" and "bioremediation in the Philippines".

Moreover, the year of publications was set between 2010-2020, and 50 items of research were set. Aside from Publish or Perish, the researcher also utilized the Mendeley search engine using the exact keywords. There were more than 200 researches gathered, including survey articles, basic research, and applied research, before cleaning but only 29 were included in the study after the cleaning which are studies conducted in the Philippines. To do this, Publish or Perish software was used and set to 100 search results while on Mendeley, it generated a search hit of approximately 200-300 results per keyword. Additionally, the researchers created a research matrix that provides the author, study's result, plant species, heavy metals, and other relevant information needed in the study. The articles' similarities and differences were considered in collecting different literature (Brevidelli & Domenico, 2008).

The researchers selected the research that will be part of the study by using these criteria: (1) only research published and indexed in a peer-reviewed journal, (2) research conducted in the Philippines setting, either in a terrestrial or water environment, and (3) published within the year 2010-2021. In analyzing the studies, the researcher employed the design of Polit et al. (2004) and Lo Biondo-Wood & Haber (2001) in which problem creation, data gathering or literature search, data assessment, data analysis, and interpretation and presentation of results are all part of the integrative review process. Data were extracted descriptively, grouped based on similarities, and classified. Both data extraction and synthesis from the articles were carried out descriptively, allowing for the observation, counting, describing, and categorizing of data to acquire information created on the issue covered in this study.

Results and Discussion

The Philippines is a country that is rich in natural resources including minerals. To maximize these minerals, mining is one of the activities used by the government to explore and collect these substances. Nevertheless, some of the minerals, specifically metals, harm the environment. Below are some of the metals mined in the Philippines and their phytoremediation.

Copper (Cu)

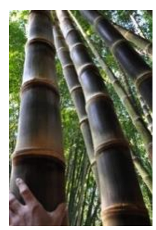
Copper is considered a toxic substance in some soils because of artificial activities like mining, smelting, agriculture, and waste disposal technologies that resulted in the release of heavy metals into the environment (Yruela, 2005). However, there are plant species that could survive and tolerate the toxicity of copper in mined and freshwater. The following are the plants considered potential phytoremediation for copper-contaminated soils and water environments.

In the study of Delos Angeles & Cuevas (2019) on the Paspalum conjugatum Berg species, they found out that this organism is copper-tolerant and is capable of growing in highly acidic soil. Thus, it can be used as an agent in phytostabilizing copper-contaminated soils due to its retaining copper in its roots. On the other hand, Paz-Alberto et al. (2015) also suggested that Sonneratia alba, Barringtonia racemosa, Bruguier sp., and Rhizophora apiculata are also potential phytoremediators of copper-contaminated sediments in mangrove ecosystems. Out of the five mangrove species that thrive in the area, Sonneratia alba and Barringtonia racemosa had the most accumulations of copper in their roots, and these species are potential phytoremediators for copper.

In copper-contaminated freshwater, plant species like *Dendrocalamus asper* and *Chrysopogon sp.* (Vetiver grass) are potential for hyperaccumulators in cleaning-up domestic and industrial wastes in ponds and river systems (Chua et al., 2019; Pleto et al., 2019). *D. asper* is considered the most efficient in Cu phytoremediation potential with a constant positive uptake of 80 M in a contaminated substrate and a bioconcentration factor of 50.57. Moreover, the accumulation of copper in *Chrysopogon sp.* and *D. asper* is mainly in the roots compared to its shoots part.

Furthermore, other plant species serve as phytostabilizer or good metal excluders. Some of these species considered potential phytoremediators for the contaminated copper-mined environment are *Eleusine indica, Pityrogramma calomelanos, Pteridium aquilinum, Dicranopteris linearis, Pteris sp., Pteris melanocaulon, Avicennia marina, Nephrolepis biserrate, Cynodon dactylon,* and *Pityrogramma calomelanos.*

Table 1. Potential Phytoremediators (Heavy Metal: Copper) in Terrestrial and Aquatic-Mined Area in the Philippines

Potential Phytoremediators	**Scientific Name/ Common Name**	**Potential Phytoremediators**	**Scientific Name/ Common Name**
 *Source: https://www.feedipedia.org/node/407*	*Paspalum conjugatum Berg*	 *Source: https://upload.wikimedia.org/wikipedia/commons/c/cd/Sonneratia_alba_1_%28 8348955883%29.jpg*	*Sonneratia alba*
 *Source: https://www.nparks.gov.sg/florafaunaweb/flora/2/7/2747*	*Barringtonia racemosa*	 *Source: http://tidechaser.blogspot.com/2011/11 /bakau-putih-bruguiera-cylindrica.html*	*Bruguier sp.*
 *Source: https://alchetron.com/Rhizophora-apiculata*	*Rhizophora apiculate*	 *Source: https://www.bambooland.com.au/dendrocalamus-asper-hitam*	*Dendrocalamus asper*
 *Source: https://www.123rf.com/photo_78083174 _vetiver-grass-or-vetiveria-zizanioides.html*	*Vetiver grass*	 *Source: https://www.researchgate.net/figure/Eleusine-indica-L-Garten_fig2_319774425*	*Eleusine indica L.*

 Source: https://www.dlium.com/2020/06/silver-fern-pityrogramma-calomelanos.html	*Pityrogramma calomelanos*	 Source: https://www.gardenia.net/plant/pteridium-aquilinum	*Pteridium aquilinum*
 Source: https://alchetron.com/Dicranopteris-linearis	*Dicranopteris linearis*	 Source: http://www.phytoimages.siu.edu/imgs/pelserpb/r/Pteridaceae_Pteris_melanocaulon_78610.html	*Pteris melanocaulon*
 Source: https://spain.inaturalist.org/taxa/75723-Avicennia-marina	*Avicennia marina*	 ource: https://www.nparks.gov.sg/florafaunaweb/flora/1/5/1554	*Nephrolepis biserrate*
 Source: https://www.mdedge.com/dermatology/article/214338/cosmeceutical-critique/cynodon-dactylon	*Cynodon dactylon*		

Table 2. Potential Phytoremediators (Heavy Metal: Lead) in Terrestrial and Aquatic-Mined Area in the Philippines

Potential Phytoremediators	Scientific Name/ Common Name	Potential Phytoremediators	Scientific Name/ Common Name
 Source: https://gobotany.nativeplanttrust.org/species/amaranthus/spinosus/	*Amaranthus spinosus*	 Source https://www.algaebase.org/search/species/detail/?species_id=ndbef37476e3d09d4	*Cymodocea rotundata*
 Source: https://www.algaebase.org/search/species/detail/?species_id=qb8efc58653c33ff1&distro=y	*Syringodium isoetifolium*	 Source: https://singapore.biodiversity.online/taxo4254/mainSpace/Thalassia%20hemprichii.html	*Thalassia Hemprichii*
 Source: https://www.alamy.com/stock-photo/enhalus.html	*Enhalus acoroides Linn*	 Source: https://www.algaebase.org/search/species/detail/?species_id=Y50db5b8d878d9878	*Halophila ovalis*
 Source: https://www.feedipedia.org/node/395	*Pennisetum purpureum*		

Table 3. Potential Phytoremediators (Heavy Metal: Nickel) in Terrestrial and Aquatic-Mined Area in the Philippines

Potential Phytoremediators	**Scientific Name/ Common Name**	**Potential Phytoremediators**	**Scientific Name/ Common Name**
 Source: http://www.phytoimages.siu.edu/img-bin/image?Violaceae/Rinorea/niccolifera/135560	*Rinorea niccolifera*	 Source: https://phytokeys.pensoft.net/article/47625/	*Phyllanthus (Phyllanthaceae)*
 Source: https://keys.lucidcentral.org/keys/v3/eafrinet/weeds/key/weeds/Media/Html/Leucaena_leucocephala_(Leucaena).htm	*Leucaena leucocephala*	 Source: https://www.nparks.gov.sg/florafaunaweb/flora/3/0/3095	*Pterecarpus Indicus*
 Source: https://www.iplantz.com/plant/1369/samanea-saman/	*Samanea saman*	 Source: https://plantingman.com/muntingia-calabura-fruit-garden/	*Muntigia calabura*
 Source: http://phytoimages.siu.edu/imgs/benctan/r/Combretaceae_Terminalia_microcarpa_28266.html	*Terminalia microcarpa*		

Table 4. Potential Phytoremediators (Heavy Metal: Mercury) in Terrestrial and Aquatic-Mined Area in the Philippines

Potential Phytoremediators	Scientific Name/ Common Name	Potential Phytoremediators	Scientific Name/ Common Name
 Source: https://www.gardenia.net/plant/imperata-cylindrica	*Imperata cylindrica L. (Cogon grass)*	 Source: https://keyserver.lucidcentral.org/weeds/data/media/Html/megathyrsus_maximus_var._maximus.htm	*Megathyrsus maximus (Guinea grass)*
 Source: https://plantvillage.psu.edu/topics/napier-grass/infos	*Pennisetum purpureum S. (Napier grass)*		

These species accumulate Cu in their roots and rhizomes, and because of this, researchers concluded that they are good phytoremediation for the copper polluted area (Merkl et al., 2005; Win et al., 2020; Claveria et al., 2010; De la Torre et al., 2016; Gabriel & Salmo, 2014; Ancheta et al., 2020).

There are also fern species with relatively high copper content in copper-arsenic mined areas in the Philippines (Claveria et al., 2019). The *Dicranopteris linearis, Histiopteris incisa, Pityrogramma calomelanos, Pteris vittata, Nephrolepis hirsutula, Pteris sp., Pinus sp., Thysanolaena latifolia,* and *Melastoma malabathricum* are fern species that can tolerate the different copper concentrations in the soil and are recommended to be the best option in post-mining rehabilitation.

However, some of these phytoremediators have a limitation, like the Dendrocalamus asper or Philippine giant bamboo (PGB). In the study of Go et al. (2019), they found out that *D. asper* is effective at low pH and elevated copper concentration. On the other hand, Pteris melanocaulon could only be used for rhizofiltration and phytostabilization but not as phytodegradation of copper and other heavy metals (De la Torre et al., 2016). Because of

these limitations of specific plant species, should be utilized in a specific copper-polluted environment.

Table 1 shows representative photos of plants from various places in the Philippines that might be used as phytoremediators to help mitigate the effects of copper pollution in terrestrial and aquatic-mined areas.

Lead (Pb)

Lead is a naturally occurring element that does not degrade over time, unlike many contaminants. Lead is persistent in the environment and can be deposited in soils and sediments as a result of lead air pollution.

Other sources of lead in ecosystems include direct garbage dumping into water bodies and mining (US EPA, 2021). Mining, smelting activities, disposal of paints, gasoline, explosives, and municipal sewage sludges have resulted in soil contamination of lead (Chaney & Ryan, 1994). To rehabilitate areas polluted by lead, some specific plants help rehabilitate the affected place.

For soil that contaminated by lead, *Amaranthus spinosus, Cymodocea rotundata, Syringodium isoetifolium, Thalassia hemprichii, Enhalus acoroides Linn, Halophila ovalis, Chrysopogon sp.* (Vetiver grass), and *Pennisetum purpureum* are the plant species that have the potential as phytoremediation (Chinmayee et al., 2012; Paz-Alberto et al., 2015; Pleto et al., 2019; Napaldet & Buot, 2020). Based on the study's result, these plant species can accumulate a higher amount of lead in their roots and leaves and potentially be phytoremediation for the said heavy metal.

On the other hand, mangrove species that have seen a potential role as phytoremediators for lead are *Sonneratia alba, Avicennia marina var rumphiana, Rhizophora stylosa,* and *Lemna minor L.* (Duckweed) (Toledo-Bruno et al., 2016; Paz-Alberto et al., 2015; Ubuza, et al., 2020). These mangrove species remove Pb from contaminated sediments directly affected by coal-fired power plants and heavy metal-contaminated water from industries. Thus, various studies pointed out that these mangrove species will be used for the phytoremediation of lead.

Table 2 depicts plants from diverse locations in the Philippines that might be employed as phytoremediators to help ameliorate the impacts of lead contamination in both terrestrial and aquatic-mined regions.

Nickel (Ni)

Nickel is a transition metal that is widely dispersed in the environment, including air, water, and soil. It can come from both natural and manmade sources. Nickel pollution may be caused by industry, the use of liquid and solid fuels, and municipal and industrial waste (Genchi et al., 2020). Kasprzak et al. (2003) stressed that human exposure to highly nickel-polluted environments, such as those associated with nickel refining, electroplating, and welding, has the potential to produce a variety of pathologic effects. However, some plant species show tolerance and characteristics that can remediate areas contaminated with nickel.

Rinorea niccolifera (Violaceae), *Phyllanthus* (Phyllanthaceae*), P. erythrotrichus, P. securinogoides, P. balgooyi, Leucaena leucocephala, Pterecarpus indicus, Samanea saman, Muntigia calabura,* and *Terminalia microcarpa* are plant species that exhibit as hyperaccumulator, phytoextraction, and rehabilitation of nickel contaminated area (Fernando et al., 2014; Quimado et al., 2014; Varela et al., 2019). It was observed that this species showed relatively high survival in the field and initial growth of height and stem diameter despite the harsh conditions. These plants can thrive in soil or water containing exceptionally high concentrations of metals, notably nickels, absorb these metals by their roots, and concentrate extraordinarily high quantities of metals in their tissues. Hence, they have the potential to be an effective phytoremediator in terms of reducing the impact of nickel on the soil.

The following photographs in Table 3 depict plants from diverse locations in the Philippines that are potential phytoremediators to help alleviate the impacts of nickel pollution in both terrestrial and aquatic mined regions.

Mercury (Hg)

It is widely recognized that all forms of mercury are hazardous, and all forms of this appear to have the potential to be converted into highly toxic monomethyl mercury, or dimethylmercury (D'Itri, 1972). In this manner, scientific approaches are needed to mitigate the presence of mercury in the environment, that plants that will serve as phytoremediation of this substance.

Imperata cylindrica L. (Cogon grass), *Megathyrsus maximus* (Guinea grass), and *Pennisetum purpureum S.* (Napier grass) are some of the plant species that exhibit tolerance and absorptive capacity in mercury-contaminated soil. Cogon grass has the highest mercury uptake with an average concentration of 10.473 ppm, guinea grass of 7.521 ppm, and Napier grass of 3..012 ppm (Abad et al., 2017). While Demetillo and Goloran (2017) found out that *Pistia stratiotes* are an aquatic plant that accumulates mercury and could be considered a potential plant for phytoaccumulation for mercury in soil sediments.

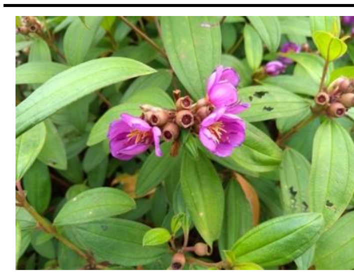
Table 4 shows plants from various places in the Philippines that might be used as phytoremediators to assist mitigate the effects of mercury pollution in both terrestrial and aquatic mined areas.

Arsenic (Ar)

Mining and processing ores in the environment have led to arsenic pollution in mining regions worldwide (Nriagu, 1994). The presence of the substance in the environment affects human health and other organisms near the polluted area. In mitigating arsenic pollution, several studies found some plant species that can become phytoremediation of the mined area.

Several studies were conducted, and it was found that these species have the potential for ecological restoration to post-

Table 5. Potential Phytoremediators (Heavy Metal: Arsenic) in Terrestrial and Aquatic-Mined Area in the Philippines

Potential Phytoremediators	Scientific Name/ Common Name	Potential Phytoremediators	Scientific Name/ Common Name
 *Source: https://www.dlium.com/2020/06/silver-fern-pityrogramma-calomelanos.html*	*Pityrogramma calomelanos*	 *Source: https://www.nparks.gov.sg/florafaunaweb/flora/1/5/1547*	*Dicranopteris linearis*
 *Source: http://phytoimages.siu.edu/imgs/BarcelJF/r/Dennstaedtiaceae_Histiopteris_incisa_59705.html*	*Histiopteris incisa*	 *Source: http://www.natureloveyou.sg/Thysanolaena%20latifolia/Main.html*	*Thysanolaena latifolia*
 *Source: https://commons.wikimedia.org/wiki/File:Melastoma_malabathricum-_Indian-rhododendron,_Palore_4.jpg*	*Melastoma malabathricum*		

mining of arsenic, namely: *Pityrogramma calomelanos* (Win et al., 2020), *Dicranopteris linearis, Histiopteris incisa, Pteris vittata, Nephrolepis hirsutula, Pteris sp., Pinus sp., Thysanolaena latifolia, Melastoma malabathricum,* and *Pteris melanocaulon* (Claveria et al., 2019). These plants are considered hyperaccumulators of arsenic and serve as good phytoremediation of arsenic in mined areas.

Finally, plants that are potential phytoremediators to help alleviate the impacts of nickel pollution in both terrestrial and aquatic mined regions are shown in Table 5.

Conclusion and recommendations

Based on the in-depth analysis of the literature reviewed, it was found that there are native plant species that can be used as phytoremediation in the heavily metal-polluted area. Some plants are grown in the area and continuously accumulate these metals in their roots, rhizomes, or shoots. It might take time to restore the polluted area, but employing phytoremediation in these areas is environmentally friendly and low-cost. Thus, the study encourages the government agencies to include the potential phytoremediators in mitigating heavy metal polluted areas in their environmental management plan. And lastly, educational institutions both in primary and higher education may develop and produce learning materials focused on the advantages of phytoremediators.

Declaration of conflict of interest

The author confirms that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

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