Selection of Potential Plants as Phytoremediation for Heavy Metals in Estuarine Ecosystem: A Systematic Review

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Abstract. The estuary area is a semi-enclosed water body area that borders the sea but still connected to fresh water from rivers. As an area that connects between sea and rivers, the estuary is an area that threatened by human activities, including water pollution of heavy metals. Therefore, it is necessary to take an action to solve the water pollution problem, especially heavy metals. Many research shows that plants have an ability to solved water pollutions, with mechanism of phytoremediation. So far, many phytoremediation researches are occupying freshwater plants, and lack of research discovered the potential of brackish water plants as heavy metals phytoremediation. Therefore, this study aims to select potential plants in an estuarine ecosystem that can be used heavy metal phytoremediation agents. This is a systematic review research that collects research has been conducted within the last five years available on the "Sciencedirect" website. Based on the result, 51 species of plants have been tested and proved as effective plants to remediate the heavy metals pollution in estuarine ecosystem. These plants are divided into three habitats, which were mangrove, coastal, and marine habitats. Furthermore, several types of heavy metals that have been discovered are Pb, Cd, Cu, Cr, Hg, Zn, Ni, As, Se, Mg, Mn, Rb, Fe, Sr, Li, Al, V, Ag, Ba, Ti, Co, Cs, Ce, Zr, U, and Y. In conclusion, according to this review, these are 51 plants have an activity as phytoremediation for heavy metals in estuarine ecosystem.

Keywords: Estuarine ecosystem · Heavy metals · Phytoremediation · Plants

1 Introduction

An estuary is a semi-enclosed body of water directly connected to the sea while also getting freshwater from rivers on land [1]. According to Wolanski & Elliott [2], an estuary is a semi-enclosed water area that is directly connected to the sea as far as the tidal limit. The estuary ecosystem is a dynamic ecosystem directly related to the high seas, where

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seawater flows with the tidal rhythm. In addition, multiple ecological parameters in an estuary area, such as temperature, salinity, turbidity, light, and flow are fluctuated. This fluctuated condition makes some species or organisms difficult to survive for a long time [3]. Furthermore, there are several types of estuaries, there are fjords, lagoons, river estuary, and creeks [4].

The estuary ecosystem is a highly threatened ecosystem caused by human activity because estuary is connected by two areas, which are freshwater river and sea. Several problems are found in the estuarine ecosystem which are pollutions, grey water, plastic waste, exploitation, and also reclamation. The most common pollutions that found in the estuary area are detergent from domestic waste and heavy metals from industrial activity. Falah [5] reported that the entry of pollutants into marine waters is mostly through rivers and accumulated in estuarine ecosystem. It is resulting many organism are difficult to survive in this area [6]. Furthermore, contaminants such as heavy metals that are accumulated in the body of organism through the food chain will disrupt the metabolic and physiological organs [7, 8]. Therefore, solution to solve the problem of water pollution in estuarine ecosystem, especially heavy metals pollution is needed.

One of the methods or technique to resolve the heavy metal pollution in estuarine ecosystem is using a plant as pollution absorbing agents. This method is called phytoremediation. Phytoremediation is one approach to remediate pollutions using a plants and microorganisms [9]. This technique is widely used with consideration of cost and environmental friendliness. Many studies have revealed the potential of several plants to remediate the environment. For example, Syranidou [10] has explained that 38 species of plants from the genus of *Juncus* have been reported to reduce heavy metal levels in coastal habitat. In addition, several types of mangroves also showed the ability to reduce heavy metal in estuarine ecosystems. The species of mangroves are *Avicennia marina, Avicennia officinalis, Rhizophora apiculata, Acanthus ilicifolius*, and several other plant species [11–14]. Moreover, another aquatic plants, such *as Sagittaria lancifolia* also has an ability to reduce heavy metals in water environment [15]. In the phytoremediation research, metal transfer factors (TF) from soil/sediment to plants or bioaccumulation factors can be used to measure the effectiveness of plants in acquiring trace metals [16, 17]. In addition, a thorough information on the extent of metal pollution of estuarine ecosystems for environmental health and living things of organism in that area are needed [18, 19].

Based on the large role of plants to resolve the waters pollutions and the fact that the quality of estuary waters is threatened, it is necessary to conduct a study that revealed species of plants have been observed to heavy metals phytoremediation activity in estuaries to develop the future research. Almost all plants can absorb the pollutions, but not all plant has an ability to absorb pollution in high concentration. An also, so far, many phytoremediation research is still using freshwater plants, and there is lack of research that are revealed the potential of brackish water plants as heavy metals phytoremediation. Therefore, this study aims to select the potential plants that grow in an estuarine ecosystem with heavy metals phytoremediation activity, obtained that reported and published in "Sciencedirect" website in the last five years. Furthermore, the results of this study are expected to be used as a basis data for determining plant species that can remediate heavy metals in estuarine ecosystem.

2 Method

This is a systematic review research. Research report are obtained from "Sciencedirect" website that published in the last five years (2016–2021). Several keywords used are phytoremediation; heavy metals; estuary ecosystem; and mangrove remediation. There were 277 papers on heavy metal estuary phytoremediation, 258 papers on heavy metal mangrove phytoremediation, and 325 on mangrove phytoremediation. The research conducted around the world which is recorded on the website. Furthermore, the data were analyzed to obtain research that matched the researcher's criteria. Then the results of the analysis will be presented in the form of descriptions and tables.

3 Results and Discussion

It was found a number of 42 papers that match researchers' criteria obtained from Sciencedirect. Furthermore, the trend oh research on the phytoremediation of estuarine plants from year to year is showed in Table 1. Based on Table 1, it can be seen that the biggest number of publications were in 2021 (9 papers), while the smallest number is in 2017 (3 papers).

3.1 Hyperaccumulation Plants

Basically, all plants have the ability to absorb pollutants in various amounts and resistance. Several species from many plant families have been shown to have more resistance to pollutants or have higher tolerant properties. This plants is called hyperaccumulator plants that able to accumulate pollutants at high concentrations in their roots and shoots [20]. Hyperaccumulator plants have several main characteristics, including having resistance to pollutants, especially metals at high concentrations in root and shoot tissues, having a higher absorption rate than other plants, and having the ability to translocate and accumulate metals from roots to all parts of the plant by high rate [21].

However, so far there is no exact value standard regarding hyperaccumulator plants [21, 22]. This means that there is no quality standard for accumulator plants to be called a hyperaccumulator plants, especially for all types of heavy metals. The term "hyperaccumulator" was first coined by Brooks [23] to define plants with metal concentrations

Table 1. Number of Publicatons

No	Years	Number of Publication
1	2016	7
2	2017	3
3	2018	7
4	2019	5
5	2020	8
6	2021	9

of more than 1% of the total dry weight in the plant canopy. In addition, Ali [24] have defined hyperaccumulator plants with a crown-root metal concentration (translocation factor, FT) greater than 1. However, FT itself cannot be considered a hyperaccumulation parameter [25].

3.2 Estuaries Plant for Phytoremediation

A critical issue is the steady release of environmental contaminants, specifically at salt marshes. Remediation of these ecosystems is hence essential for both their protection and to stop the spread of contaminants into the food chain. Due to their potential for using phytoremediation to remediate metal-contaminated media, salt marsh plants have been recommended as appropriate options for remediating soil and sediment.

Based on the literature data processing results, it is known that several types of plants in the estuary area have been tested for their ability to remediate heavy metals in the area. However, in some studies, they have also conducted experiments in the laboratory. Estuaries are made up of many different types of habitats. These habitats can include oyster reefs, coral reefs, rocky shores, submerged aquatic vegetation, marshes, and mangroves [49]. In this article, author categorizes plant species based on vegetation formations which are differentiated based on their floristic structure and composition. The divisions are coastal vegetation (Table 2), mangrove vegetation (Table 3), and submerged aquatic vegetation (Table 4) [26].

Table 2. List of plants in coastal vegetation

NO	LIST OF PLANTS	ABSORBED HEAVY METALS	REFERENCES
1	*Elytrigia repens,* *Galium verum,* *Phragmites australis.*	As, Cr, Cu, Pb, Zn	[26]
2	*Halimiome portulacoides*	Ce	[27]
3	*Halimiome portulacoides,* *Spartina patens*	Cu, Zn, Pb, As	[28]
4	*Artiplex halimus*	Cd	[29]
5	*Artiplex halimus*	Cu	[30]
6	*Ipomoea pes-caprae*	Cr, Cd, Pb	[31]
7	*Juncus krausii*	Cu, Zn, As, Se, Cd, Pb	[32]
8	*Juncus maritimus*	Hg	[33]
9	*Phragmites australis*	Fe, Mn, Zn, Pb, Ba, Cr, As, Cu, Ni, Co, Mo, Cd, Se, Hg	[34]
10	*Phragmites australis*	Cd, Cr, Zn	[35]
11	*Phragmites australis,* *Suaeda salsa*	As, Cd, Cr, Cu, Pb, Zn	[36]

(*continued*)

Table 2. (*continued*)

NO	LIST OF PLANTS	ABSORBED HEAVY METALS	REFERENCES
12	*Sisymbrium officinale, Plantago lanceolata, Parietario judaica, Oenanthe crocato, Cakile maritima, Silene gallica, Plantago coronopus, Anagallis arvensis, Veronica anagolis-aquatica*	Li, Be, Al, V, Cr, Co, Cu, Ni, Zn, Mo, Ag, Cd, Sb, Ba, Ti, Pb, U	[37]
13	*Porteresia* sp.	Fe, Zn, Mn, Cu, Co, Rb, Sr, Pb	[38]
14	*Sarcocornia quinqueflora*	Zn, Cu, Pb, Cd	[39]
15	*Sesuvium portulacastrum*	Cu, Zn, Cd	[40]
16	*Sesuvium portulacastrum*	Cd	[41]
17	*Sesuvium portulacastrum*	Cu	[42]
18	*Spartina alterniflora*	Cr, Pb, Cu, Zn, Mg	[43]
19	*Spartina densiflora, Spartina maritime*	Cu, Zn, Ni	[44]
20	*Sporobolus virginicus*	Zn, Cu, Pb, Se	[14]
21	*Suaeda australis*	Cu, Zn	[45]
22	*Suaeda fruticosa*	Zn	[46]
23	*Suaeda heteroptera, Nereis succinea*	Cu	[47]
24	*Typha latifolia, Panicum maximum, Scirpus lacustris*	Pb, Cd, Ni, Zn	[48]

The result showed that 51 plant species had been estimated for their ability to absorb heavy metals in estuarine ecosystem. As many as 26 types of heavy metals were found in this area, including lead (Pb), cadmium (Cd), copper (Cu), chromium (Cr), mercury (Hg), zinc (Zn), nickel (Ni), arsenic (As), selenium (Se), magnesium (Mg), manganese (Mn), rubidium (Rb), iron (Fe), strontium (Sr), lithium (Li), aluminium (Al), vanadium (V), silver (Ag), barium (Ba), titanium (Ti), cobalt (Co), caesium (Cs), cerium (Ce),zirconium (Zr), uranum (U), and yttrium (Y).

Table 1 showed the species of phytoremediator plants in coastal habitats. Generally, this habitat is occupied by creeping plants that cover the coastline. Another characteristic in general, these plants are herbaceous plants with deep roots, resistant to drought, and have low soil nutrients and wind [50, 51]. The species of plants are *Elytrigia repens,* *Galium verum, Pragmites australis, Halimiome portulacoides, Spartina patens, Artiplex halimus, Ipomoea per-carpe, Juncus* spp, *Suaeda salsa, Sysygium officinale, Plantago lanceolata, Parietario judaica, Oenanthe crocato, Cakile maritima, Silene gallica, Plantago coronopus, Anagalis arvensis, Veronica anagolis-aquatica, Porteresia* sp. *Sarcocornia quinqueflora, Sesuvium portulacastrum, Spartina spp. Sporobolus virginicus Nereis Succinea, Typha latifolia, Panium maxicum,* dan *Scirpus lacustris*. In a study conducted by Harmesa & Cordova [31] it can be seen that the *katang-katang* plant (*Ipomoea pes-carpe*) is able to absorb chromium (Cr), cadmium (Cd), and lead (Pb) metals in their bodies in concentration of 1.2 mg/L, 0.4 mg/L, and 1.23 mg/L. Table 2 also showed several genus of plants that mostly used as phytoremediation, namely *Phragmites, Juncus, Sesuvium*, and *Suaeda*. The most common heavy metals were absorbed by the plants are copper (Cu), lead (Pb), and zinc (Zn).

Several plants that have been mentioned above are reported to have an ability to have phytoremediation activity towards heavy metals in coastal habitat. This activity related to their high tolerance for salt and other abiotic stresses such as heavy metals [52]. Therefore, coastal plants have the potential to be used as heavy metals phytoremediation in estuaries. Furthermore, Lutts [53] have reported that many areas in the world are contaminated with heavy metals. Moreover, based on their high ability to absorb various heavy metal elements, plants in coastal habitats can be utilized as bioindicators to detect local ecosystem contamination [52, 54–56]. In addition, one of advantages of coastal plants for heavy metals phytoremediation are their root morphology is able to resist erosion because the roots are able to bind sand [55].

Table 3 showed the species of phytoremediation plants in the habitat of mangroves or better known as mangrove forests. Many of the mangrove species have the potential as heavy metal hyperaccumulator plants. Titah [61] reported an experiment using *Avicennia marina* & *Avicennia alba*, which are proved to be able to accumulate Cu in concentration of 110 mg/L & 83.8 mg/L and Cr in concentration of 90.8 mg/L & 55.3 mg/L recpectively. In addition, there are also many studies conducted with various species of mangroves such as *Avicennia germinans, Avicennia officinalis, Rhizophora apiculata, Sonneratia alba, Aegiceras corniculatum, Bruguiera cylindrica, Kandelia obovata, Bruguiera gymnorrhiza, Rhizophora stylosa* dan *Acanthus ilicifolius*. From Table 3 it can be seen that several genus of plants that mostly used as heavy metals phytoremediation are *Rhizophora*, and *Avicennia*. The most common heavy metals found are copper (Cu), chormium (Cr), and zinc (Zn). Figure of these plants showed in Fig. 1.

Mangroves are phytoremediator agents because their growth location is very prone to be exposed by pollutants. Therefore, besides having ecosystem functions (such as carbon sinks, wave barriers, erosion barriers, and food sources), mangroves have been subjected to reduce contamination significantly. The increasing industrial development conditions rapidly, pollutants, heavy metals, are released into the sea through estuaries and wetland waters and cause ecosystem imbalances [66, 67].

Table 3. List of plants in mangrove habitats

NO	LIST OF PLANT	ABSORBED HEAVY METALS	REFERENCES
1	*Aegiceras corniculatum, Avicennia marina*	Sb	[57]
2	*Avicennia alba, Acanthus ilicifolius*	Fe, Ti, Zr, Rb, Zn, Sr, Pb, Y, Cu, Cr	[58]
3	*Avicennia germinans*	Cd, Pb, As	[59]
4	*Avicennia marina*	Cu, Zn, Hg, Ni, Cr, V, Co	[13]
5	*Avicennia marina*	Cr, Cu, Ni, Pb, Zn	[60]
6	*Avicennia marina, Avicennia alba*	Cu, Cr	[61]
7	*Avicennia officinalis, Sonneratia alba*	Fe, Cr, Co, Ni, Zn	[12]
8	*Bruguiera cylindrica*	Cu	[62]
9	*Kandelia obovata, Aegiceras corniculatum, Avicennia marina, Acanthus ilicifolius, Bruguiera gymnorhiza, Rhizophora stylosa*	Cu, Cr, Zn, Pb	[63]
10	*Rhizopora apiculata*	As, Zn, Mn, Pb, Cu	[11]
11	*Rhizophora mucronata*	Cd, Pb, Cu, Zn	[64]
12	*Rhizopora apiculata*	Cr	[65]

(a) (b)

Fig. 1. The most abundant species of plants used as phytoremediator agent in mangrove habitat. (a) *Rhizophora apiculata* (b) *Avicennia marina* (location: mangrove center Ujungpangkah, Gresik, East Java) (privat property right)

Plants in the submerged habitat also have an ability to remediate heavy metals pollutions, as shown in Table 4. Several plants are proved to have ability to absorb heavy metal pollutions, for example seagrass plants. For example, a study on seagrass *Zostera marina* was reported as a phytoremediator of several types heavy metals, such as cobalt (Co),

Table 4. List of plants in submerged aquatic

NO	LIST OF PLANTS	ABSORBED HEAVY METALS	REFERENCES
1	*Enhalus acoroides*	Cd, Cu, Ni, Pb, Zn	[68]
2	*Myriophyllum spiculatum*	Co, Cs	[69]
3	*Porphyra umbicialis, Enteromorpha sp.*	LI, Be, Al, V, Cr, Co, Cu, Ni, Zn, Mo, Ag, Cd, Sb, Ba, Ti, Pb, U	[37]
4	*Zostera japanica*	As, Cd, Cr, Cu, Pb, Hg, Zn.	[70]

zinc (Zn), lead (Pb), and mercury (Hg) [71]. Furthermore, several species of seagrass have been tested for their ability to absorb heavy metals, there were *Enhalus acoroides, Myriophyllum spiculatum*, and *Zostera japonica*. Based on several studies, seagrass is considered to be used as a bioindicator and a solution to overcome heavy metal pollution in the ocean. This is due to the seagrass is able to absorb and accumulate heavy metals in its body in a high index and still survived in the long time [72].

Beside seagrass, several species from seaweed, namely *Porphyta umbicialis* also able to absorb Zn, Se, Mo, Ba, and Cd metals in concentration of 1.46 mg/L, 1.54 mg/L, 6.84 mg/L, 1.80 mg/L, and 4.81 mg/L respectively [37]. Furthermore, algae *Enteromorpha* sp also reported that has an ability to accumulate Be, Al, and Se heavy metals in concentration of 0.46 mg/L, 0.41 mg/L, and 0.81 mg/L respectively. In addition, many studies have shown that macroalgae could absorb metals in water and sediments, indicating that they are suitable bio indicators of metal pollution [73, 74]. Furthermore, macroalgae can withstand vast temperature and salinity fluctuations and thrive all year, which are critical properties for effective pollution bioindicators. [37, 75]. In submerged ecosystem (Table 3), it was found as many as 21 types of heavy metals, considered that in submerged ecosystem are highly polluted. Thus, a sollution to solve the heavy metals pollutions in urgently needed.

This finding leads us to determine the species of plants that reported to have phytoremediation activity towards many kinds of heavy metal that harmful for the environment. This finding will be further followed up by laboratory experimental on selected plants and the result will be useful for government to grow more plants that have phytoremediation activity in estuarine ecosystem.

One example of model or construction that able to use on phytoremediation in estuaries ecosystem is use "TertraPOT" Fig. 2. This model was first introduced by Wang in 2016 [76]. Unlike other tetrapods, the TetraPOT is partially hollowed out to provide place for a biodegradable pot insert, soil, and root growth area. The pre-seeded layers will begin to degrade as the tides rise, allowing the mangrove trees to grow their root systems via three lower apertures. The marine defense system will become stronger over time as a TetraPOT's roots entwine with those of its neighbors as well as the beach, lowering the possibility of dislodgment as show as Fig. 3. Additionally, the mangroves will increase biodiversity in the area and improve air and water quality. Hopefully, this action will significantly reduce heavy metals that harm for human metabolism when they are consumed through living organisms such as contaminated fishes.

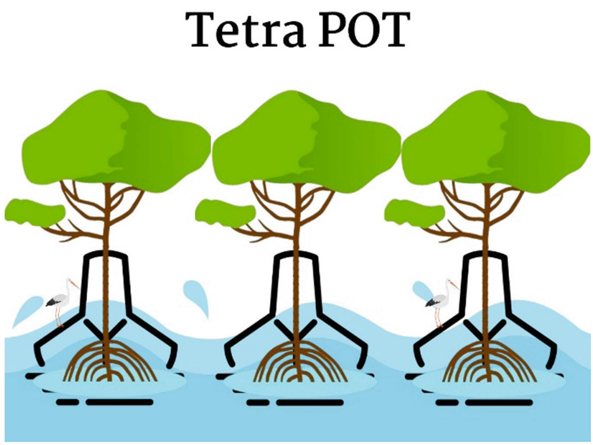

Fig. 2. "TetraPOT" uses mangroves.

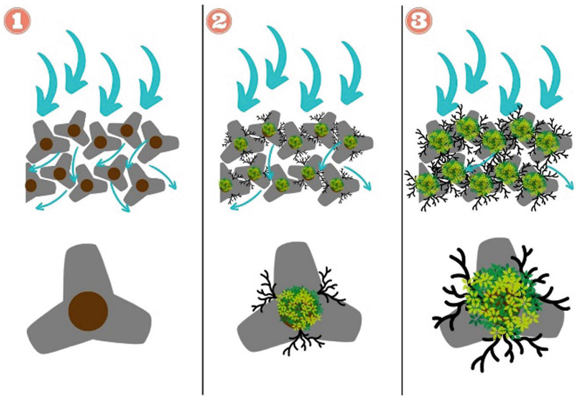

Fig. 3. Mechanism of "TertaPOT" to reinforce sea defense systems.

In addition, from 42 number of papers collected by the method, it was found that as many as 51 species of plants have been tested and proved as effective plants to remediate the heavy metals pollution in estuarine ecosystem. These plants are divided into three types of habitats, which are mangrove, coastal, and marine habitats. Furthermore, several types of heavy metals that have been discovered to be accumulated in these plants are Pb, Cd, Cu, Cr, Hg, Zn, Ni, As, Se, Mg, Mn, Rb, Fe, Sr, Li, Al, V, Ag, Ba, Ti, Co, Cs, Ce, Zr, U, and Y.

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