A review: The use of mangrove for biomonitoring on aquatic environment

R Wilda, A M Hamdan* and R Rahmi
Department of Environmental Engineering, Faculty of Science and Technology, UIN Ar-Raniry Banda Aceh, Indonesia, 23111
Email: abd.mujahid.hamdan@gmail.com

Abstract. Mangroves have been investigated widely as plants that can absorb and accumulate heavy metals in their tissues. Due to that ability, mangroves have been used to reduce heavy metals in the aquatic environment. Furthermore, mangroves have been used for biomonitoring of heavy metals pollution. The use of mangroves for biomonitoring on aquatic environments has been considered as a cheap, rapid, and sufficient method. The mangrove is an organism that has the ability to absorb the contaminants of heavy metal and to function as fine pollutants trap. However, to develop this technique for wide use, research and investigation are still needed. This paper is aimed to describe the future direction of mangrove studies of using mangroves as a biomonitoring agent. Based on the review, *Rhizophora mucronata* and *Avicennia marina* are mangrove species that have a promising ability to be used for biomonitoring in the aquatic environment.

1. Introduction

Industrialization and urbanization have increased the anthropogenic contribution of heavy metals in the biosphere [1-4]. Domestic waste is a major source that contributes to the pollution of the environment [5]. The effect of anthropogenic has altered metal mobility and diversity [6-7]. Human activities in industrial sector, such as mining industry, as well as domestic activities, have a significant contribution to the increasing of heavy metals both in the air and the soil [8-9]. According to [10] the aquatic environments of Indonesia are suspected in certain areas to be contaminated by organic contaminants such as oil, detergent, and organic materials in the form of domestic sewage from the auto industry. In addition, heavy metals are one type of contaminants that attracts attention globally. The heaviest metals contaminant encountered in the aquatic environment [11,12,13]. Sources of heavy metal pollutants can be from mining operations [14] printing, electronic industry, waste [15] traffic activities, dust emissions, and agricultural activities [16]. The pollutants in the water not only can cause a decline in water quality, but also affect public and environmental health and environment health [17,18]. Therefore, the monitoring of heavy metals is necessary to provide a base controlling and maintaining environmental continuity.

Biomonitoring is an environmental monitoring technique that uses certain organisms or bioindicators that can provide information on the changes and quality of the environment [19-23]. Biomonitoring can be an excellent technique for monitoring surface water pollution such us rivers and ocean pollution [24]. Biomonitoring has been used to analyze various types of environments, both environments that change due to anthropogenic activities such as industry and housing, as well as environmental changes due to the influx of pollutants from natural sources [25,26].
In practice, the indicators used in biomonitoring can be animals, microorganisms, humans, and plants. One of the plants that are extensively used in biomonitoring is mangrove plants. Mangrove plants are plants that are commonly found in Indonesia such as in Sumatra, Java, Papua, Sulawesi, and Kalimantan. Mangroves are a community of plants that live in highly saline environments that are affected by tides [27]. The ecosystems of mangroves are intertidal ecosystem where are located between the marine and terrestrial environments in tropical and subtropical areas [28]. Mangrove forest ecosystems provide a variety of ecological benefits, including protection against flooding, prevention of coastline erosion, buffering salinity, and abundance of biodiversity [28].

Ecosystems of mangrove have the ability to tolerate heavy metal in their environment [29,30]. A number of studies have indicated that the plants are able to limit the mobility of contaminants in estuary environments [31]. One of the ecological functions of this plant is to resist toxic material [32,13] and to absorb heavy metals from the environment [33]. Therefore, mangroves have been used as bioremediation agents for heavy metals in the aquatic environment [34,35]. Because of its ability to accumulate heavy metals, the presence of heavy metals in their leaves can be a proxy of heavy metals abundance in the aquatic environment. The heavy metals that can be absorbed by mangroves including Cr, As, Al, Cd, Cu, Mn, Fe, Mo, Pb, Ni and Zn [36,37]. This paper aimed to review the mangroves’ abilities as a heavy metal indicator in the aquatic environment.

2. Accumulated heavy metals in the mangroves foliage
The mangrove species differ in their ability to tolerate and absorb heavy metals from the environment into their foliage. The difference is caused by the dissimilarity of the root system of each species [33]. In certain conditions, mangroves will be stressed and they cannot grow properly [38]. For example, mangrove species such as Excoecaria agallocha have a higher toxicity in the absorption of Pb in the roots than in the leaf tissue [39]. Heavy metals such as Cu, Zn, Cd, and Hg generally indicate high bioconcentration factors at the root, while the concentration factor for the leaf is usually much lower than the other parts [40,38]. Meanwhile, the type of Avicennia marina in translating Pb to leaves is lower than to the roots [41].

Table 1 shows several reports that use mangrove plants to reduce heavy metal content in water. Although different species, mangrove plants have a function as pollutant traps in absorbing various heavy metal elements in their environment. Avicennia marina and Rhizophora mucronata are mangrove species that have an excellent capability to absorb heavy metals such as Hg, Mn, Zn, Cr, Cu, Cd and Pb [40-43]. A. marina is a mangrove that is mostly found in coastal areas. The root of R. mucronata is hanging and has oval-shaped leaves [44]. According to [45], the roots foliage are the higher tissues in accumulation of heavy metals, because the roots are in direct contact to the sediments. Meanwhile, the absorption ability of heavy metals in mangrove species is differentiated by their root system [33]. The root surface of Rhizophora is broader than the root surface of Avicennia, so the ability of Rhizophora tends to be greater than Avicennia [42].

3. Mechanism of mangroves in accumulating heavy metals
Heavy metals from industrial waste are one of the most destructive contaminants for aquatic ecosystems. Heavy metals introduced into the water will be precipitated to the sediment. The sedimentation process occurs due to the unbiodegradable character of heavy metals, then it will affect the life of aquatic biota such as shellfish, shrimp, and crabs [50]. Furthermore, they affect the food chain system. The heavy metals that transport into the aquatic environment are generally ionic. The heavy metals in the form of compounds such as oxides, sulfides, hydroxides, and carbonate compounds are dissolved easily in the water [37]. A high concentration of heavy metals both essential and non-essential can affect plant growth, even they can threaten plant growth [51]. Therefore, the plants have mechanisms to minimize metal toxicity [18,52-57].
Table 1. Mangroves species that have been used in biomonitoring of heavy metals in the aquatic environment.

| Species              | Metals | Root (ppm) | Leaf (ppm) | Stem (ppm) | Fruit (ppm) | References     |
|----------------------|--------|------------|------------|------------|-------------|----------------|
| Avicennia marina     | Cu     | 23.674     | 16.567     | 21.674     |             | Handayani, 2006 |
|                      | Cd     | 15.303     | 16.567     |            |             |                |
|                      | Zn     | 21.143     |            |            |             |                |
| Rhizophora mucronata | Cu     | 24.431     |            |            |             |                |
|                      | Cd     | 21.342     |            |            |             |                |
|                      | Zn     | 19.546     |            |            |             |                |
| Avicennia marina     | Pb     | 2,19       | 3,54       | 5,89       | 1,71        | Arisandy, 2012 |
| Avicennia marina     | Pb     | 0,0912     |            |            |             | Wulandari, 2018|
| Rhizophora mucronata | Pb     | 0,0916     |            |            |             |                |
| Avicennia marina     | Cu     | 7,17       | 7,76       |            |             | Awaliya, 2018  | [46]          |
|                      | Pb     | 2,30       |            |            |             |                |
| Avicennia marina     | Hg     | 0,002      | 0,026      | 0,059      |             | Heriyanto, 2011| [48]          |
|                      | Pb     | 5,21       |            |            |             | Ali, 2012      |               |
| Rhizophora mucronata | Hg     | 13,82      | 110,81     | 66,70      |             |                |
|                      | Pb     | 5,19       | 8,03       | 10,39      |             |                |
| Sonneratia alba      | Pb     | 4,15       | 3,74       |            |             | Khairuddin, 2018| [35]          |
|                      | Cd     | 0,19       | 0,24       |            |             |                |
| Rhizophora Apicullata| Pb     | 1,85       | 3,21       |            |             |                |
|                      | Cd     | 0,18       | 0,41       |            |             |                |

The presence of heavy metals has an impact on the aquatic plants, including mangroves plant. The heavy metals in the mangrove tissues are entered by the mechanism of transportation of heavy metals from the environment into plant organs [58]. The heavy metals that enter into the mangroves tissues are accumulated. The heavy metals are in the form of anion and cation that are through the root systems [59,56]. The absorption occurs through the root epidermis [43]. The process of root system in absorbing is called rhizofiltration. This is a process in which plant roots absorb and precipitate heavy metals [60,37]. According to Rohmawati [61] the accumulation of heavy metals into plant roots by molecular transport in the root membrane, then form a complex metal transport to the xylem. Furthermore, absorption occurs in the two processes, including (i) absorption of ions directly into a meristem cell, and (ii) absorption of ions in the leaves. The mechanism of heavy metal accumulation in mangroves can be seen in figure 1.

Figure 1 is the absorption process of heavy metals in mangroves. The mechanism of absorbing heavy metals depends on the root surface and nutrients [62]. The heavy metal transportation and absorption through plasma membrane and tissue of secondary carrier such as a channel protein or H⁺ carrier protein, where membrane negative potential encourages cation uptake through secondary
carrier [33]. Then, the cations are released into the xylem which is assisted by a protein-carrying membrane. Phytocelatin and metallothionein are transport tissues that have a fundamental role in translocating of heavy metals [33]. Phytocelatin is a group of proteins that contain amino acids such as cysteine, glycine, and glutamic acid. These proteins will induce plants if the plant is stressed by heavy metals [63,64]. Phytocystalline binds the heavy metal ions, and then transport them to vacuoles. While metallothionein tissue space stored for excess heavy metal ions, then it also transports protein for excess heavy metals from cells to other cells. Factors that influence the transportation of organic substances in plants are: 1) pressure from the roots that push water upwards, 2) leaf transpiration, and 3) capillarity of xylem [65].

![Figure 1. Mechanisms of heavy metals accumulations of mangroves plants.](image)

The ability of the accumulation of heavy metals in mangrove plants can be determined by using bio concentration factor (BCF) and translocation factor (TF) [66,40]. BCF is used to determine the ability of plants to accumulate heavy metals in roots or leaves to the heavy metal concentrations within sediments [33]. The values > 1000 indicates high ability of acculation, the values of ≥ 250 are medium ability and the values of BCF <250 are low ability. The translocation factor can be used to measure the amount of heavy metal transferred from one organ to another [2, 67-50].

4. Potential use of mangroves
The mangrove forest ecosystem is one of the most prolific and unique [70]. Mangrove vegetation that grows in coastal waters is part of the coastal ecosystem which has the highest level of productivity compared to other coastal ecosystems. The presence of mangrove ecosystems in coastal waters
became vital because mangrove vegetation has the ability to accumulate heavy metals and to reduce the concentration of pollutants in the water [71]. Mangrove are mainly in tropical and subtropical zones [72]. Indonesia has the largest mangrove forest in the world. The Indonesian mangroves forest covers more than 50% of Asia's and nearly 25% of the world's mangrove forests [73]. Indonesia has long coastline, ± 95,181 km where a portion of the coastal area is covered with mangrove forests [74]. The Indonesia mangrove forests are amazingly varied because of the remarkable diversity of physiological conditions on the coast of Indonesia [75,76].

In Indonesia, the mangrove ecosystem is one of the resources endangered in the coastal zone. Anthropogenic is a major contributor to the degradation of mangrove forests, such as agriculture that uses chemicals, industry, and mining [77]. In the last three decades nearly 50% of the total degradation rate of mangrove forests in Indonesia had been lost. About 6.7 million ha is left to be around 3.2 million ha [78]. Logging is one of the causes for the decreasing of mangrove population. Excessive logging has a significant effect on species diversity and natural wealth. Mangrove populations that are converted into functions such as land use as fish ponds, which then influence the concentration of heavy metals in mangrove sediments [79]. The use of mangrove plants in Indonesia is usually used for risk reduction to catastrophic events such as abrasion and a drop of the land as a result of increasing population around the coastal that could result in the rob flood. The root system of mangroves reduces soil erosion and helps to stabilize the nearby coastal landscape. Another role of the mangrove ecosystem could be developed as a medium to neutralize the heavy metals in its surroundings. The followings are the roles of mangrove forests that are very important for the environment and humans: (1) to protect coastal areas from distractions and to provide habitat for different animal species, (2) as pollinators and carbon storage [80] (3) as a barrier to waves and protect from coastal erosion, (4) as an upbringing as a place to feed biota and spawn areas for various kinds of aquatic biota, (5) as strategic places for people who like fishing and as place for ecotourism (6) economically mangrove plants can be used as construction materials, firewood, roofs, docks, traditional medicine and handicrafts [81] mangroves are plants that have ability as hyperaccumulator.

Moreover, another role of the mangrove as a beach buffer against natural disasters such as tsunami of hurricane waves and extreme waves [82]. Mangroves do not only play an important role in ensuring the sustainability of coastal ecosystems, but also in providing important socio-economic benefits for communities around the coast [83]. Awareness of the use of mangrove waters is very influential on the state of the environment is polluted, and mangrove ecosystems that have various functions such as the function of ecological, social and economic [84]. Therefore, a monitoring of metal pollutants is necessary to provide a basis for controlling pollution, and biomonitoring is one way to tackle the problem of pollution since it reflects metal biocapability [85].

5. Conclusion
The use of mangroves for biomonitoring of heavy metals is very appropriate. Based on the review, *Rhizophora mucronata* and *Avecennia marina* are mangrove species that have a promising ability to be used for biomonitoring in aquatic environment. The mangrove is an organism that has the ability to absorb the contaminants of heavy metal and to function as fine pollutants trap. The mangroves also play a major role in the prevention of disasters.

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