

AN INTRODUCTION TO FLOATING TREATMENT WETLANDS AND ITS APPLICATION POTENTIAL FOR REMEDIATION OF CITARUM WATERSHED, INDONESIA

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Graphical abstract



Abstract

Floating Treatment Wetlands (FTWs) are considered the most applicable and cost effective instrument for aquatic pollutant removal. This aquaponic-based bioremediation has become a potential alternative solution since inorganic (physical and chemical) treatment is seen to be ineffective for large-scale polluted objects. Numerous investigations have proved that FTWs are potential to decrease major pollutant concentration in water e.g., nitrogen, phosphate, as well as heavy metals. This treatment is applicable by using different macrophytes species. Depending on its pollutant target, the use of macrophytes will vary to its pollutant which will be removed. There are only limited reports available relating to application of macrophytes as pollutant removal applied in Indonesia. Citarum watershed is known as one of the most polluted aquatic area in Indonesia. It urgently needs a suitable method of water pollutant removal in this area. This paper aims to describe the application of FTWs as one of remediation methods that harnesses a significant potential because of its low-cost, eco-friendly, and sustainable nature for water restoration.

Keywords: Citarum, floating treatment wetland, pollutant removal, water remediation

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1.0 INTRODUCTION

Industrial and population growth provides many advantages for human life. High technology and economic growth have become an ideal condition for the communities. Nevertheless, negative impacts are produced during its processes. Environmental degradation is one of the main produced impacts that should be treated. Water degradation is becoming an issue for environmentalist due to its essential function for many organisms. Water pollution may be defined as degradation of water quality due to decreasing living support factor in water or increasing amount of hazardous materials in water. Water health parameters are commonly composed by

normal concentration of nitrate, nitrite, dissolved oxygen, dissolved chemicals, and the absence of heavy metals [1–4]. It is undeniable fact that healthy water ecosystem will support life and maintaining the organism diversity. Economic benefit will follow this condition, then. Polluted water ecosystem had been becoming an issue which should be a priority treat to urge. There are various methods are tested by environmental researchers to restore healthy water ecosystem condition e.g., usage of bioremediation bacteria, application of active carbon, floating wetland installation, etc. [5–9].

Floating treatment wetlands (FTWs) method has seen as the most applicable water remediation system. This method is firstly observed in 1717 and originally applied

in order to decrease high concentrated organic compound in water that would trigger algal blooms [9-12]. FTWs are also considerable as low cost remediation system. This system does not require high energy and intensive maintenance to ensure its functionality during treatment [13, 14]. In the world, FTWs system is applied in several nations for various remediation objects and aesthetic purposes e.g. New Zealand, Australia, Singapore, China, United States, and Alaska [15].

Aquatic pollution is a significant issue in Indonesia, especially in urban river area. The major pollutant sources are contributed by agricultural, industrial, and municipal activities. All those pollutants are commonly distributed by river stream, then, produce wider environmental destruction. There are several rivers in Indonesia notorious for their highly polluted condition i.e., Citarum, Cisadane, Citanduy, Bengawan Solo, Progo, Kampar, Batanghari, Musi, Barito, Mamasa, and Brantas. Citarum (see Figure 1) These rivers have been known as the most polluted river in Indonesia.

Geographically, it is connected two capital cities, Bandung and Jakarta. Citarum river is laid across three large reservoir in West Java i.e., Saguling reservoir (S 6° 55' 5.9916", E 107° 25' 4.7064"), Cirata reservoir (S 6° 44' 19.2582", E 107° 17' 29.2524"), and Jatiluhur reservoir (S 6° 33' 32.904", N 107° 19' 43.0464"). Citarum watershed covered more than 6 000 km² area, approximately, and floods nine regencies in West Java province, i.e. Bandung, Bandung Barat, Subang, Purwakarta, Karawang, Sumedang, Cianjur, Bekasi, and Indramayu. Those areas are containing over 5.3 to 11.5 ×10⁵ inhabitants, approximately [16, 17].

Here, a brief review of application FTWs potency for Citarum watershed remediation is informed. Through this review, an objective to restore aquatic environment is importantly need and to put a new milestone for a strategic and effective remediation managements for a better aquatic environment condition.

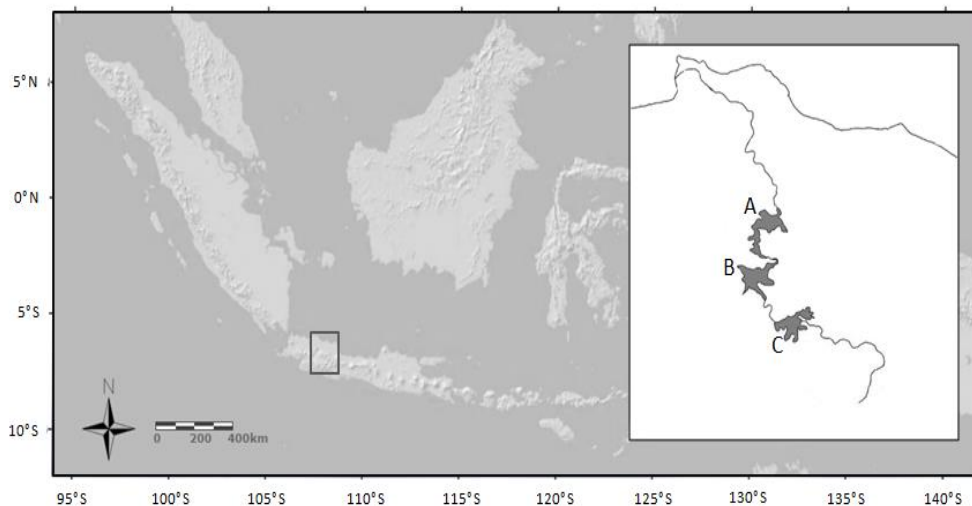


Figure 1 Location of Citarum watershed (square). Inserted picture showed the main Citarum River (under consideration) and three connected reservoirs (Jatiluhur reservoir, A; Cirata reservoir, B; Saguling reservoir, C). Coordinate information are available in text

2.0 FLOATING TREATMENT WETLANDS (FTWs)

2.1 Macrophytes Species for FTWs

FTWs are originally developed from phytoremediation technique by using macrophytes as it pollutant removal. There are numerous applications of water plants for this purpose. It is an interesting point that every species has their specialized characteristic in pollutant removal. There are major considerations in selecting certain plant to be applied in FTWs i.e., the plants habitat suitability and their abilities for pollutant uptaking [18]. Nevertheless, there are some reports of the initiation of the application of terrestrial plants for aquatic remediation [14, 15, 19, 20]. Specified use of

selected macrophytes could be differentiated based on the targeted pollutant. The main water contaminants are usually contributed by total amount of nitrate (TN), total phosphate (TP), and heavy metals. Those contaminants significantly triggered water degradation [21-23]. According to Indonesian Ministry of Environment decree (No. 115/2003), it has been decided that several standard parameters are used in claiming good water quality. Those parameters are composed of four physical parameters, 33 anorganic parameters, four organic parameters, and two microbiological parameters. It is obvious that the application of macrophytes will be mainly affected by the organic compound concentration especially in eutroficated water [24-27]. Currently, the applications

of several macrophytes for heavy metals uptake studies are also intensively conducted [18, 23, 28].

Positive results reported from these investigations [29-31].

Table 1 Several reported potential macrophytes species candidate for FTW-based surface groundwater remediation

| | Removed contaminants | | | | | | | | | | | | Ref. | |
|-----------------------------|----------------------|---|----|----|----|----|----|----|----|----|----|----|------|--------------------------|
| | N | P | As | Br | Cr | Co | Cu | Cd | Mn | Fe | Ni | Pb | | Zn |
| <i>Eichhornia</i> spp. | • | • | • | | | • | | | | | | • | • | [13, 21, 32] |
| <i>Pistia</i> spp. | • | • | | | | | | | | | | | | [15, 19] |
| <i>Ipomoea aquatica</i> | • | • | | | | | | | | | | | | [10, 15, 19] |
| <i>Phragmites australis</i> | • | • | | • | | | | | • | | | | | [10, 15, 19, 31, 33, 34] |
| <i>Typha</i> spp. | • | • | | • | • | • | • | | • | | • | | • | [10,13,14,28,31,33-35] |
| <i>Juncus effuses</i> | • | • | | | | | | • | | • | | | • | [12, 30, 31, 36] |
| <i>Scirpus maritimus</i> | • | • | | | | | | | • | • | | | | [31, 37] |
| <i>Irish</i> spp. | • | • | | | | | | | | | | | | [9, 14] |
| <i>Pontederia cordata</i> | • | • | | | | | | | | | | | | [12] |
| <i>Carex riparia</i> | • | • | | | | | | • | | | • | | • | [10, 30] |
| <i>Canna</i> sp. | • | • | | | | • | • | | | | | | • | [10, 28] |
| <i>Pontederia cordata</i> | • | • | | | | | | | | | | | | [9] |

Eichhornia sp., *Irish* sp., and *Typha* sp. are three most well-studied species for aquatic remediation. There are several investigation conducted related to these species [10, 14, 21, 38-41]. *Eichhornia* sp. has become a well-observed plant for its ability in adsorb nutrition excess [38, 39]. In Indonesia, water hyacinth has become the common floating plants which can be easily found in wetland area. In the other case, it is mentioned that water hyacinth presence are no longer beneficially for the environment. It is due to this species is considered as common invasive and harmful weeds [42]. Nevertheless, water hyacinth provides potential ability for nutrition excess reduction due to its rapid growth in eutroficated water. An investigation regarding to controllable method of water hyacinth for FTWs is important prior to applied.

Irish sp. and *Typha* sp., as well as water hyacinth, provide similar function in removing nitrate and phosphate excess in water [10, 14]. Table 1 shows several investigated macrophytes for environment remediation. It is shown that pollutant accumulation abilities are found to be selective among treated plants. Highest selectivity for pollutant compounds removal is more observable for heavy metals uptake in macrophytes. For an example, *Typha* spp. are reported for their ability for broader heavy metals accumulation ability (Br, Cr, Co, Cu, Mn, Ni, and Zn) while others showed plant (in Table 1) provide more specified heavy metals to accumulated. Identification of hyperaccumulator macrophytes may provide the successful FTWs application. Hyperaccumulator macrophytes defined for their abilities in 10 to 500 times pollutant accumulation abilities than ordinary plants [43]. Detailed hyperaccumulator criteria and the examples have been described by Chibuike and Obiora [43]. This information provided a new challenge to get better understanding in macrophytes selection to apply in certain aquatic environment.

2.2 Pollutant Removal Effectivity

Pollutant removal effectivity has showed for their high variation among numerous investigated macrophytes. Pollutant uptake rates depend on involved several biochemical processes in plants i.e., phytoextraction, phytostabilization, and phyto-volatilation [43]. Those processes rate will significantly effected to the uptake rate. Nevertheless, an integrated and detailed study to observe phytoextraction, phytostabilization, and phyto-volatilation remain limited. It is still unclear information regarding to the most affected factor for macrophytes pollutant selectivity. Hence, there are numerous publications showed these phenomena are existed in broad macrophytes species [13, 31, 43-45].

Most of the reported macrophytes are proved for their abilities in N and P removal. This abilities is predictable because those compound are rolling as essential nutrition for most primary producers. Important results are achieved by investigating several treated heavy metals. Heavy metals removals selectivity among various plants information has been provided by Teuchies *et al.* [31].

It has been observed by the use of 29 macrophytes exposed in nine different metals. It has been known that all of those plants do not only absorb metals selectively, but there are different maximum pollutant uptake concentration as well as the uptake rate. For an example, it is comparable that *Typha latifolia* accumulate Mn 483 $\mu\text{g g}^{-1}$ (68.80 % from total exposed Mn) higher than *Juncus effuses* which is only take 140 $\mu\text{g g}^{-1}$ (19.94 % from total exposed Mn). Nevertheless, *Typha latifolia* is having less abilities in accumulate Cr, Cu, and Cd (1.03 %, 4.83 %, and 1.22 % from total exposed metals, respectively) than *Juncus effuses* (1.48 %, 8.11 %, and 26.44 % from total exposed metals, respectively) [31]. Through this information, it is suggestible that effective FTW method should notice the targeted pollutant for macrophytes selection consideration. Thus, intensive

and advanced studies to screen the removal effectivity on broad macrophytes species should be conducted.

3.0 APPLICATION POTENCY OF FTWS FOR CITARUM WATERSHED

Citarum watershed is known as the important stormwater due to its various functions in supporting life for many fresh water animals as well as high density human population in West Java. Three man-made reservoirs in this watershed provide multifunction for human activities, i.e., aquaculture area, water storage, and electricity generator [16]. These areas are also important in order to maintain water availabilities for downstream area such as Jakarta, capital city of Indonesia. By all beneficial factors provided by Citarum watershed, there is a great issue regarding pollutant load exposed to aquatic environment of Citarum due to its efficiently in transporting anthropogenic and other pollutants [46]. The recent Citarum watershed pollution investigation is conducted by Marganingrum *et al.* [47]. By using Pollution Index (PI) method, it is reported that those areas are categorized as moderately to heavily polluted (PI scale 5 to 15) since 2002 to 2010. PI method allowed investigator to identify the main parameter which contributed to higher PI index. It is found that fecal coliform is identified as the most contributed parameter. This finding indicated that Citarum watershed pollution may triggered mainly by municipal and agricultural activities. Furthermore, Cahyaningsing and Harsoyo [47] provided an effort to acquired larger information by investigating sub-watershed area. It is known that the most heavily contaminated Citarum sub-watershed area is found in upperstream. This area is found to have high density population, intensive agricultural and industrial activities.



Figure 2 Commercial FTWs applied in different locations, i.e. New Zealand (A), Shanghai (B), Canada (C), and Singapore (D) [48]

Detection on high concentration contaminant in Citarum watershed is attracting several concerned parties in Indonesia, including the government. Several strategies have been applied to decrease the pollutant input in to the water i.e., enjoyment of free flow industrial waste, garbage managements, and society building in order to prevents higher pollution. Nevertheless, an effort to restore damaged aquatic environment and water quality is not conducted intensively. There are several obstacles relating to Citarum watershed remediation planning, wide coverage area, less funding availability, and pessimistic opinion and cooperation from the society are caused well-managed remediation is not getting proceeded effectively.

By the entire complex obstacles remained, a potential and effective method for Citarum watershed remediation is urgently needed. Here we proposed a developed method to restore water quality in storm water which is come from a phytoremediation technique by using floating structure. This FTWs method is designed to be deployable in wide and open aquatic environment to absorb pollutant presences. This method potency has been investigated in many wetland areas in the world. A successful application achieved by Chang *et al.* [12] in a mesocosms system (stormwater-pond environment). FTWs deployment resulted nutrition levels decreased more than 50 %, approximately. Furthermore, larger environment system for FTWs investigation reported by Zhu *et al.* [49] and Zhao *et al.* [50]. It has been tried a FTWs system in the open river for 130 d. It is resulted that FTWs system proved its suitability for river area. Other FTWs investigations in macrocosm area are also proved that this system is potentially applicable in an open environment with minimum destructive effects [51, 52]. Currently, commercial FTWs system has been introduced (Figure 2) to the consumer. In addition, offer than one thousand FTWs-related patents have been registered till 2015. Even though, FTWs is still improved to be advanced scientifically.

4.0 CONCLUSION

Floating treatment wetlands offers a new approach for applicable surface water remediation, especially in Indonesia. Pre-remediation management strategy is an important point to achieve successful deployment of FTW. Macrophytes selection for its environment suitability, pollutant uptake rate, hyperaccumulator plant selection, and pollutant-posed resistance are few factors that should be identified prior to application. Presently, this phytoremediation method is continuing to become interesting topic to study and new approaches for FTWs will keep growing to be advanced.

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