Evaluation of Plant Structure in Urban Lake Ecosystem and Their Performance in Treatment Wetland Systems (TWS) to Maintain Lake Water Quality in Megacity Jakarta, Indonesia

Cynthia Henny1* and Riky Kurniawan1
1Research Center for Limnology, Indonesian Institute of Sciences, Jl. Raya Bogor km 46, Cibinong, Indonesia

*Email: cynthia@limnologi.lipi.go.id

Abstract. Urban lakes have become important city landscape to help maintaining the balance of hydrology (groundwater and surface) and ecology in urban ecosystem. Due to experiencing encroachment and severe pollution problems, the lakes require urgent handling and management. One of the promising alternative solutions of lake restoration and management is applying ecosystem-based approaches and/or green technology such as treatment wetland systems using plants. This paper will review various types of tropical plants (terrestrial and aquatic plants) and evaluate their role in maintaining urban lake water quality in megacity Jakarta and their performance in treatment wetland systems from our previous and on-going studies. Plants with more important role to contribute to improve lake water quality are the submerged and emergent plants. The most common and robust types of aquatic plants in less abundance and balanced plant structure and composition at the lake shoreline and littoral area with controlled submerged plants and no indication of invasive species give better lake water quality of urban lakes. The most robust type of aquatic plants and few types of terrestrial plants studied could give significant nutrient and solids removal efficiency in both constructed and floating treatment wetland systems. Using plants with ecosystem-based approaches according to plant structure at the lake surroundings and in the treatment wetland systems could contribute to maintain better urban lake water quality.

1. Introduction
Most of urban lakes in Urban lakes have become important city landscape to help maintaining the balance of hydrology (groundwater and surface) and ecology in urban ecosystem. By contributing to the amenity and to mitigate the urban climate, urban lakes can significantly provide better quality environment to live in urban centers. Rapid urban development and lacking of sanitation facility has led to lakes encroachment and severe pollution. Direct or indirect garbage dump, untreated sewage and storm water runoff has caused lake water quality degradation, siltation/sedimentation and hyper-eutrophication [1,2,3]. Lakes require urgent handling and management to restore the ecosystem health given that the lakes are used for water supply for drinking water plant, irrigation and fishery, recreational area and for fishing activity [1,2].

One of the promising alternative solutions of lake restoration and management is using ecosystem-based approaches and/or green technology such as treatment wetland system. The role of plants in maintaining healthy aquatic ecosystem and in treatment wetland systems (TWS) have been well documented. The use of plants to treat wastewater and excess nutrient in the water bodies have been
worldwide [4,5,6,7]. Plants structure and composition at lake shoreline landscape and littoral area can act as bio-filter to entrap the contaminants/solids in the storm water, run off and untreated sewage which enter the lakes. The plants at the lake riparian and littoral area could slow down the storm water and surface run off flow and subsequently entrap and uptake the contaminants by root systems. Aquatic plants (emergent, floating and submerged) in littoral area could also serve as habitat and provide food for fish and another aquatic biota (4,5,8,9). Plants also have been known to play an important role in the TWS to reduce the contaminants in the wastewater and to improve lake water quality. Various types of plants have been reported to have good performance removing solids, organic waste, nutrients, toxic substances and even coliform and pathogenic bacteria. The aerial tissue, the tissue in the water, root system in the sediment or freely floating in the water contribute to all process in the TWS including physical, chemical and biological process to reduce the pollutants in the waste water and the polluted lake water. Pollutant removal by the plant system in the TWS could be via nutrient uptake and pollutant transformation. As in the floating treatment wetlands, root network system provides surface area for biofilm which is responsible for biochemical transformation of contaminants [6,7,10,11,12,13,14].

This paper will review various types of tropical plants (terrestrial and aquatic plants) and evaluate their role in maintaining urban lake water quality in megacity Jakarta and their performance in treatment wetland systems from our previous and on-going studies in Research Center for Limnology-Indonesian Institute of Sciences (RCL-LIPI) and other previous studies (in Indonesia and in other countries) as well.

2. Role of Plants

Natural lakes usually have surrounding area which consist of buffer, riparian and littoral zones with different plant structure and composition. Here in this paper we focus on riparian and littoral area where plants mostly play important role in maintaining good water quality and healthy ecosystem. At the riparian area from the buffer zone to the lake shore line, the plant structure may consist of forest type of trees, bushes, and grasses. At the littoral area, the plant structure may compose different types of aquatic plants (emergent, floating and submerged) which all have different roles in ecosystem (Fig. 1) [15].

Balanced plant structure could prevent the lake pollution from storm water run-off and sewage inflow. The plants at littoral area especially could entrap the solids, uptake nutrient, toxic metals by the root system thereby reducing the risk of siltation, water pollution and eutrophication. Furthermore, plants also provide habitat for aquatic biota [4,5,8,9]. Natural submerged plants have been reported to be able to restrain resuspension of bottom sediments and phosphate release from the sediments to improve lake water quality of a eutrophic shallow lake [16] while Xu et al. [17] indicates that controlled biomass of submerged plant improve lake’s ecological health. Re-establishment of natural submerged plants is important to manage a long-term stability for clear water conditions [18,19].

Plants are important component that have several roles in relation to wastewater treatment processes such as in treatment wetland systems (TWS). TWS combine physical, chemical and biological processes in treating wastewater, where plants can synergize with microbes attached on the bed media and associated with plant root systems (rhizosphere) [6,10,12, 20]. Plants with high biomass productivity provide the energy source to the microbes and other organisms associated with the media and plants in TWS. Plants used in TWS are mostly the aquatic plants such as emergent plants (aerial stem and leaves with root in sediment); floating plants (freely floating plants or floating leaved with root in the sediment); and submerged plants (tissue entirely submerged in the water). Although several emergent plants from terrestrial can be adapted to grow on the TWS with some water level or in saturated media/substrate of TWS.
Summary of the roles of aquatic plants either lake ecosystem and/or in all TWS types (surface water flow (SWF), subsurface water flow (SSF), floating treatment wetland (FTW) and hybrid (combined SWF and SSF)) can be seen in table 1.

Table 1. Brief summary of plants (aquatic plants) role in lake ecosystem or treatment wetland system (Kedlec and Wallace [6], Brix [10], Shelef et al [11], Tanner and Headley [13], Jethwa and Bajpal [20], Henny and Meutia [21])

| Plants property                      | Role in the treatment process                                                                 |
|--------------------------------------|-----------------------------------------------------------------------------------------------|
| Aerial plant tissue                  | Light attenuation (reduce eutrophication), reduce wind and run-off velocity (reduce risk of resuspension, erosion), effect of microclimate, nutrient sink, aesthetic, microhabitat for fauna, insulation |
| Plant tissues in water               | Biofiltration, bioretention, reduce run-off and current flow (increase sedimentation and reduce resuspension of solids), Pollutant uptake and, microhabitat, increase/transfer oxygen in the water (stimulate aerobic microbial degradation), decrease pathogens |
| Roots and the rhizomes in sediment   | Maintain the water flow in the substrate (prevent clogging), release of the oxygen (increase microbial degradation), stimulate biofilm growth, pollutant uptake (especially nutrient), stabilize bed sediment |
| Roots system for floating plants or emergent plants in FTW systems | Stimulate microbial biofilm, Increase oxygen in the water, nutrient and pollutant uptake, habitat for aquatic fauna |

3. Plants structure and composition and the relation to urban lake water quality in megacity Jakarta

Despite having multifunction especially as water resources, urban lakes city of Jakarta and surrounding (Megacity Jakarta) area were not managed properly. As results of that, most of the lakes are in unhealthy ecosystem condition. Due to rapid urban development around the lakes, encroachment, lack of open space to develop green structure and pollution problem are unavoidable. The lakes have left with very minimized buffer zone at lake riparian area to develop vegetated surrounding area as common perceived in natural lakes. The most common mis-management of urban lakes in megacity Jakarta is by building concrete wall at the lake periphery and not developing natural shoreline. Most of lakes are without shore and not allowing natural wetland to be established in the lake littoral area. Followings are our previous studies on the plants structure and composition at the lake riparian and littoral area in several lakes in megacity Jakarta (Table 2-4; Fig. 2). Here we divide the lakes into 3 categories such as
lakes in planned residential or in rural-urban area (ruban), less dense populated area (sub-urban village) and dense populated are (urban village) [23]. Most of lakes with concrete shoreline or at least half of it. Although several lakes or reservoirs have been rehabilitated, the lake water quality is still in poor condition, most have eutrophication problem. Part of it due to lack of plant structure at the lake riparian especially no littoral area developed on the lake shoreline. The two lakes with better water quality observed are in the planned residential area and rural-urban area with more natural shoreline and surroundings where balanced plant structure with moderate abundance and composition both at riparian and littoral areas are observed (Table 2). While the lakes in sub urban-village with part natural and concrete or all concrete shoreline, there is no submerged plants, and most of the trees plants are not forest types (Table 3). The lakes riparian area used for agriculture have high risk eutrophication problem.

**Table 2.** Plant Structure and composition at the riparian and littoral area of several urban lakes in planned residential area in Megacity Jakarta (Henny and Meutia [21], Kurniawan and Henny [22], Kurniawan and Henny [23])

| URBAN LAKES | LITTORAL ZONE | RIPARIAN ZONE |
|-------------|---------------|---------------|
|             | Submerged     | Floating leaves rooted in sediment | Free Floating | Emergent | Shubs | Trees |
| CHUNI       | Hydrilla verticillata | Ludwigia sp., Pistia sp., Salvinia sp. | Salvinia sp. | Cyperus platystylis, Eleusine indica, Brachiaeria matica, Paspalum sp., Paspalum sp., Digitaria sp. | Musa sp., Ageratum conyzoides, Eupatorium odoratum, Mimosa pudica, Clitoria ternatea, Caesalpinia sp., Celosia argentea, Pteris sp., Alternanthera sp. | Pine trees, Muntingia calabara, Bauhinia purpurea |
| CIBUNU      | Myriophyllum verticillata | Ludwigia sp. | Typha angustifolia, Brachiaeria matica, Panicum repens, Ischaemum sp. | Manihot utilissima, Musa sp., Ageratum conyzoides, Eupatorium odoratum, Mimosa pudica, Celosia argentea, Alternanthera sp., Pteris sp. | Erythrina crista-galli, Cocos nucifera, Muntingia calabara, Manilkara kauki, Ficus benjamina, Artocarpus altillis, Artocarpus sp., Swietenia macrophylla, Cynas sp., Morinda citriflora, Averhoa bilimbi, Bauhinia purpurea |

The worst lake water quality is in the urban center with packed housing and very dense population. Beside the lakes receive sewage from residential area, lake surroundings are lack of plants structure, less diverse with very small number of plants observed. Some lakes are having problem with water pollution, hyper eutrophication and invasive macrophytes such as *Eichornia crassipes* (Table 4; Fig. 2). In addition to balanced plant structure and composition at the lake surroundings, shoreline development also appears to have effect on lake water quality and eutrophication problem. The studies indicate that the lakes with more natural-vegetated shoreline would likely to have better water quality and lower risk of eutrophication problem and overabundance of invasive macrophytes than the lakes with concrete
embankment. Increasing urban vegetation will increase nutrient retention and limit exports and therefore reduce nutrient and pollutant input to the lakes.

Table 3. Plant Structure and composition at the riparian and littoral area of several urban lakes in less dense populated area in Megacity Jakarta (Henny and Meutia [21], Kurniawan and Henny [22], Kurniawan and Henny [23]).

| URBAN LAKES     | LITTORAL ZONE            | RIPARIAN ZONE             |
|-----------------|--------------------------|----------------------------|
|                 | Floating leaves          | Free Floating              | Emergent          | Shrubs                      | Trees                     |
|                 | rooted in sediment       |                            | Cyperus sp.       | Musa sp., Eclipta prostata, | Cocos nucifera, Roystonia |
|                 |                          |                            |                   | Mimosa pudica,              | regia, Cerbera manghas,   |
|                 |                          |                            |                   | Caladium sp.               | Muntingia calabara,       |
|                 |                          |                            |                   |                            | Mangifera indica,         |
|                 |                          |                            |                   |                            | Ficus elastica            |
| CIPONDOH        | Ipomoea aquatica         | Eichornia crassipes        |                  |                            |                          |
| Sub-urban village, natural surroundings, one third of surface area covered by Eichornia, slightly turbid water, invasive macrophyte |
| GINTUNG         | Ipomoea aquatica         | Eichornia crassipes        |                  | Manihot utilisima, Musa    | Nephelium lappaceum,      |
| Sub-urban village, natural and concrete shoreline, aquaculture, turbid water, eutrophication |         |                          | sp., Ageratum conyroides, | sp., Ageratum conyroides, | Cocos nucifera, Muntingia |
|                 |                          |                            | Eupatorium odoratum,| Mimosa pudica,              | calabara, Manilkara       |
|                 |                          |                            |                   | Cyrtostachys sp,           | kauki, Bambusa sp.        |
|                 |                          |                            |                   | Dracaena sp.               |                            |
| BABAKAN         | Ipomoea aquatica         | Eichornia crassipes        |                  | Musa sp.                   |                             |
| Sub-urban village, concrete shoreline, eutrophication, slightly turbid |
|                 |                          |                            |                  |                            |                            |

Figure 2. Several urban lakes water quality condition in Megacity Jakarta

The clear water lakes observed from our previous studies were clearly due to the presence of emergent and especially submerged plants which contributed most to the nutrient uptake. Controlled submerged and emergent plants usually prevent algal bloom/lake eutrophication and can maintain good water quality in the lake. Only lakes with controlled submerged plants have more clear water indicating that submerged plants clearly play more important role on the prevention of resuspension of bottom sediments and phosphate release from the sediment [16,17,18,19]. Other important aspect to allow the submerged plants develop and to avoid them becoming invasive is keeping the lake shore with certain
slope and depth and maintain more natural shoreline. Kolada [5] indicated that the lake morphology influenced the trophic status of lakes and alteration of aquatic plant structure resulted in eutrophication. Undisturbed condition and the shape of littoral habitat affect development of plant structure and community.

**Table 4.** Plant Structure and composition at the riparian and littoral area of several urban lakes in densely populated area in Megacity Jakarta (Henny and Meutia [21], Kurniawan and Henny [22], Kurniawan and Henny [23])

| URBAN LAKES       | LITTORAL ZONE                                      | RIPARIAN ZONE                                      |
|--------------------|---------------------------------------------------|---------------------------------------------------|
| **RAWA BADUNG**    | Floating leaves rooted in sediment                | Free Floating                                     |
| Urban village,     | Lemnaperpusilla, Echorniacrospes                   | Cyperus sp.                                        |
| restored grey water| Eichorniacrassipes                                 | Eichorniacrassipes                                |
| color              |                                                   |                                                   |
| **RAWA BESAR**     | Ipomoea aquatica                                  | Cyperus sp.                                        |
| Urban village,     |                                                   |                                                   |
| concrete           |                                                   |                                                   |
| surrounding,       |                                                   |                                                   |
| receive domestic   |                                                   |                                                   |
| wastewater,        |                                                   |                                                   |
| aquaculture,       |                                                   |                                                   |
| hypereutrophicatio |                                                   |                                                   |
| n                  |                                                   |                                                   |
| **RAWA KALONG**    | Ipomoea aquatica, Ludwigiaadscendens              | Cyperus sp.                                        |
| Ruban village,     |                                                   |                                                   |
| concrete           |                                                   |                                                   |
| surrounding,       |                                                   |                                                   |
| receive domestic   |                                                   |                                                   |
| wastewater         |                                                   |                                                   |
| aquaculture,       |                                                   |                                                   |
| eutrophication     |                                                   |                                                   |
| **PLUIT**          | Ipomoea aquatica                                  | Amaranthus sp.                                     |
| (reservoir- urban   |                                                   |                                                   |
| area- restored),   |                                                   |                                                   |
| grey water color   |                                                   |                                                   |
| **RIA RIO**        |                                                    |                                                   |
| (reservoir), urban  |                                                    |                                                   |
| village, restored, |                                                    |                                                   |
| greywater color,   |                                                    |                                                   |
| some part          |                                                    |                                                   |
| eutrophication     |                                                    |                                                   |
The most common and robust types of plants found at the lake riparian and/or littoral area of urban lakes in megacity Jakarta are followings: *Hydrilla verticillata* and *Myriophyllum verticillatum* (submerged plants); *Eichornia crassipes, Ipomoea aquatica, Lemma minor* (floating plants), *Mimosa pudica, Ageratum conyzoides* (shrubs), *Cyperus sp.* (emergent plants), and *Muntingia calabara* (trees).

### 4. Performance of Plants in Treatment Wetland Systems (TWS)

Beside mentioned in table 1, the most important role of plants in TWS is removing the pollutant from the contaminated water either by retaining the solids, nutrient or pollutant uptake, pollutant transformation and degradation via synergism with biofilm, microbes in the rhizomes. Followings are the performance of plants in TWS to treat various contaminated waters form previous and on-going research in Research Center for Limnology (RCL) (Table 5). High pollutant removal efficiency (RE) by plants in TWS for free water surface depends on initial pollutant concentration in the influent, loading rate, hydraulic retention, and types of plants, and for the subsurface flow the types of bed media will likely determine the performance of TWS.

**Table 5. Performance of plants in treatment wetland systems (TWS) from our research center previous studies**

| Plant species | Types of wastewater (WW) | Types of TWS | Performance (Removal Efficiency (%)) | References |
|---------------|--------------------------|--------------|--------------------------------------|------------|
| *Canna indica, Hydrilla verticillata, Nymphaea stellata, Lemma minor* | Tapioca WW | SSF - SWF | Increase DO, pH, SS (97); COD (72.98), TOM (52.48), turbidity (87.9) | Meutia and Satya [25] |
| *Typha sp, Lemma minor, Hydrilla verticillata* | Laboratory WW | SSF - SWF | SSF: SS (80.43), TOM (45); SWF: SS (54.96), TOM (38.69%) | Meutia [26] |
| *Typha sp, Ipomoea aquatica, Eichornia crassipes, Hydrilla verticillata, Lemma minor* | Domestic WW, Aquaculture | SSF - SWF | BOD (15 - 95), COD (15-75), TOC (34-95), TN (10-73), TP (10 - 10), Coliform bacteria (14 - 100) | Meutia [27] |
| *Lemnaperpusilla, Pistia stratiotes, Eichorniacrassipes, Spirodellapolyrizha* | Urban lake water | SWF | *Eicornia and Pistoria: TSS (81.48), TOM (51.21), TN (85.82), TP (24.07); Lemma and Spirodella: TSS (79.63), TOM (26.18), TN (78.95), TP (100) | Chrismada et al [28] |
| *Typhas, Lepironiasp, pyrite mineral* | Cr(VI) plating waste | SSF | Cr(VI) (99.86) | Susanti et al [29] |
| *Cyperus papyrus, Echinodoruspalaefolius, Oryza sativa* | Sewage | SWF | TSS (50 - 60) | Henny et al [30] |
| *Hybiscussp, Canna indica, Typhasp, Cyperussp, Pitsisisp* | Palm Oil Mill Effluent | Hybrid (SSF - SWF) | COD (98), TSS (95), TN (80), TP (85), Increase DO, pH and TDS | Henny et al [31] |
| *Heliconiadensiflora, Vetiveriacizaniodes, Echinodoruspalaefolius* | Livestock waste | FTW | *Heliconia: TSS (64), TN (79.64), TP (55), Vetiveria: TSS (43), TN (61), TP (61.2), Echinodorus: TSS (41), TN (59), TP (50.24) | Kurniawan and Henny [32] |
Heliconiadensiflora, Vetiveriazizanioides, Myriophilluvercillatum

Urban lake water FTW Heliconia: TN (18 - 68), TP (21 - 45), TSS (15 - 45); Vetiveria: TN (12 - 66), TP (19 - 42), TSS (12 - 36); Myriophillum: TN (33 - 71), TP (39 - 62), TSS (18 - 62)

Henny et al [33]

Canna variegata, Vetiveriazizanioides, Cyperussp, Echinodorussp, Limnocharissp

Lake water SWF, FTW TN (40 -80), TP (15 - 50), Chlorophyll-a (50), Increase DO level, N (35.6 g/m^2), P (2.34 g/m^2) removed

Henny et al [34]

Echinodoruspaleofolius

Aquaculture SSF TSS (95), TN (98), TP (99)

Henny and Wijayanti [35]

Typhasp, Cyperussp

Aquaculture SWF TSS (75), TN (65), TP (55)

Henny and Gunawan [36]

SWF: Surface water flow; SSF: Subsurface flow; FTW: Floating treatment wetland

Subsurface flow is the most studied TWS with the similar types of plants applied. Other previous studies in Indonesia reported several plants including Chrysopogon zizanioides, Cyperus papyrus, Phragmites australis, Echinorpus palaeofolius, Echinorpus amazonicus in SSF-TWS to treat various waste ranging from grey water to gold mining wastewater. The plants used in the TWS have high removal efficiency on COD, TSS and nitrogen, but not phosphate [37, 38, 39, 40, 41]. The types of plants used in our previous and on-going studies on treatment wetland system in Research Center for Limnology are presented in figure 3.

As in the floating treatment wetlands (FTWs), plants with the long and dense root networks determine the performance of the system. The plants root systems/the rhizome and microbial biofilm associated with it play important role for the nutrient or the pollutant uptake, transformation and degradation. The plants and the root system in the FTWs also provide the habitat not only for economic local lake’s aquatic life but also for other type of terrestrial fauna. Different trophic levels were observed to inhabit and/or just visit the FTWs indicate that the plants in the FTWs could serve either as feeding ground or foraging place, a place for reproduction, nursery and a place for shelter [34, 43, 44].
As comparison to other tropical and subtropical countries the summary performance of TWS with the plants used in the system presented in table 6. Subsurface flow and hybrid TWS apparently have better pollutant RE compare to SWF system alone especially for high loading rate of pollutant regarding the types of plants used. *Phragmites australis, Cyperus papyrus, Typha angustifoli, Pontederia and Canna indica* are the emergent plants mostly used in TWS especially for SWF and SSF types of TWS. *Phragmites, Typha* and *Cyperus* are most plants applied in TWS globally. Plants increase the removal of solids, organic carbon and nitrogen but less for phosphate in the TWS. The bed media of SSF-TWS apparently contribute to high phosphate removal efficiency. *Eichornia crassipes, Pistisia stratiotes* and *Lemnanor* are the free-floating plants commonly used in the TWS. Our previous studies indicate that *L. minor* has higher removal of phosphate and *P. stratiotes* has higher removal of nitrogen. Although it can be used in the TWS, the most rapid growth *E. crassipes* could give problem if applied directly in the ecosystem such as floating treatment wetland (FTW) application. *E. crassipes* is invasive plant and usually found covering major lake surface in which could lead to lake siltation and decrease local fish population due to lake low oxygen content [21]. Which plants can contribute higher treatment efficiency in the TWS are still being understood completely. The types of plants (native or exotic), plant growth rate, number and density, good natural adaptation, good root development, resistant to the occurrence of pest or disease, regeneration and ease of natural propagation, easy getting seedlings, level of pollutant/nutrient load that plant can tolerate, harvesting strategy, oxygen supply to roots and type of microbial biofilm growth on root surface will affect the performance of TWS [6, 20, 43, 44]. In the FTW for instance good root development and harvesting strategy determine the efficiency of treatment. Field application on lake water, harvesting strategy is accountable to calculate nutrient/pollutant removal and give maximum pollutant/nutrient removal as well [44,45].

**Table 6.** Summary of performance of plants in treatment wetland systems (TWS) from tropical and subtropical area (Zhang et al [12])

| Plant species | Types of wastewater (WW) | Types of TWS | Removal Efficiency (%) |
|---------------|--------------------------|--------------|------------------------|
|               | TSS  | BODs  | COD  | NH₄-N | NO₃-N | TN   | TP   |

**Figure 3.** The plants used in our previous and on-going studies on treatment wetland system (left to right above: *Cyperus papyrus, Cyperus*, *Typha*, *Canna indica, Echinodorus palaeofolius*; below: *Vetiver zizanioides, Heliconia densiflora, Canna variegata, Echinodorus palaeofolius, Heliconia densiflora*).
Phragmites spp, Typha spp, Cyperus spp, Canna indica, Pistia sp, Eichornia crassipes, Scirpus grossus

| Approach                  | Plant Selection                                    | SWF   | HSSF  | VSSF  | Hybrid  |
|---------------------------|----------------------------------------------------|-------|-------|-------|---------|
| Municipal, Industrial WW, | Phragmites spp, Typha spp, Cyperus spp, Canna     | 78.07 | 82.6  | 84.9  | 91.3    |
| Sugar factory WW,         | indica, Pistia sp, Eichornia crassipes, Scirpus   | 77    | 78.3  | 87.6  | 81.6    |
| Greywater, Lake water,    | grossus                                             | 77.3  | 70.6  | 64.1  | 84.3    |
| Stormwater (secondary,    |                                                     | 65.4  | 62.6  | 64.1  | 80.7    |
| tertiary)                 |                                                     | 75.3  | 42.5  | 73.3  | 80.8    |
| Municipal, Swine           | Phragmites spp, Typha spp, Cyperus spp, Canna     |       |       |       |         |
| effluent, Greywater,      | indica, Pistia sp, Eichornia crassipes, Scirpus   |       |       |       |         |
| Blackwater (secondary)    | grossus                                             |       |       |       |         |
| Municipal, Livestock WW,  | Phragmites spp, Typha spp, Cyperus spp, Canna     |       |       |       |         |
| Landfill leachate, Lake   | indica, Pistia sp, Eichornia crassipes, Scirpus   |       |       |       |         |
| water (secondary)         | grossus                                             |       |       |       |         |
| Municipal, Livestock WW,  | Phragmites spp, Typha spp, Cyperus spp, Canna     |       |       |       |         |
| Landfill leachate, Agricultural WW, Winery, Laboratory | indica, Pistia sp, Eichornia crassipes, Scirpus |       |       |       |         |
| WW(secondary)             | grossus                                             |       |       |       |         |
| Urban catchment, Storm     | Canna indica, Typha sp, Vetiver, Polygonum sp,     | 46.6  | 80.8  | 85.4  | 85.4    |
| water, Municipal WW,      | Eichornia crassipes, Pontederia cordata, Juncus    | 70.7  | 50.7  | 60.1  | 64.3    |
| Agricultural runoff,      | spp, Lemna sp, Iris sp                              | 55.2  | 50.7  | 64.3  | 54.1    |
| River water               |                                                     | 63.6  | 50.7  | 64.3  | 54.1    |

SWF: Surface water flow; HSSF: Horizontal subsurface flow; VSSF: Vertical subsurface flow; Hybrid: Combined SSF and SWF; FTW: Floating treatment wetland

Green technology using plants with ecosystem-based approaches and in treatment wetland systems can be a promising alternative solution for lake restoration and management especially for urban lakes in Megacity Jakarta with degraded water quality and unhealthy ecosystem. Combined ecosystem-based approaches and the hybrid TWS (combined SWF and SSF) could be applied to treat sewage/waste water and prevent the storm water and surface run off before entering the lake. The floating treatment wetlands (FTWs) could be applied to treat lake water directly on the lake surface for the lakes with concrete embankment or without natural shoreline. The FTWs can be placed to intercept the inflow or around the lake periphery.

Native/local plants selection for lake surrounding management according to plant structure on lake shoreline area should be a priority. Although native plants should be better selection to avoid invasive species, but mostly studied are the most robust type of plants in the TWS due to high level pollutant load tolerance. The most robust type of plants is still global type of plants. The plant selection also depends on what the source and target pollutant to be treated. Subsurface flow TWS which can be applied as popular rain garden to treat storm water and surface runoff may use less robust type of plants with flower to provide the aesthetic to the city. Plants with the flower such as Iris, Canna, Pontederia and Heliconia can be used for that purpose. Future studies should consider more native plants to be applied in the TWS. The use of TWS plants for commercial purposes should be considered in the future. For instances part of the plants, leaves or stem can be used for crafting, for animal feeding, or produce other product with economical values. TWS application using various plants should be a necessity in today’s eco-city concept to improve urban lake water quality and in addition to contribution of climate change mitigation [46].

5. Conclusion
The most common of plants found at the urban lake riparian and littoral area of urban lakes in megacity Jakarta are the most robust and global ones. Less abundance and balanced plant structure and composition at the lake shoreline and littoral area with the presence of controlled submerged plants with no indication of invasive free-floating plants give better lake water quality. Phragmites australis, Echinodorus paleofolius, Vetiveria zizanioides, Canna indica, Heliconia sp., Cyperus papyrus are among the plants in both constructed and floating treatment wetland systems that have better nutrient, organic material and solids removal efficiency. The most robust type of plants can be used in both treatment wetland systems are P. australis, C. papyrus, E. paleofolius and H. densiflora. These plants can be applied in SWF and/or SSF-treatment wetland system to treat surface run-off or sewage channel or other wastewater discharge entering the lake and lake water directly using floating treatment wetland for urban lakes water quality management in the long term in Megacity Jakarta.

Acknowledgements
The authors would like to thank Saepul, the librarian in Research Center for Limnology in collecting some references.

References
[1] Henny C and Meutia AA 2014 Limnotek. 21 2
[2] Henny C and Meutia AA 2014 Proc. Environ. Sci.20 737
[3] Hendrawan D 2005 Water Quality of Rivers and Lakes in the Capital City of Jakarta. Maka. Teknol. 9 (1) 13
[4] Wetzel R G 2001. Limnology: River and lake ecology (San Diego - Academic Press) 1006 pp
[5] Kolada A 2014 Ecol. Indicat.38 282
[6] Kadlec R H and Wallace S D 2009 Treatment Wetlands. 2nd ed. (United States of America: CRC Press)
[7] Zhang D Q, Jinadasa K B S N, Gersberg R M, Liu Y, Ng W J and Tan S K 2014 J. Environ. Manage.141116
[8] Gettys, L A, Haller W T and Petty D G 2014 A best management practices handbook. 3rd ed AERF (Wisconsin- Fond du Lac) 235 pp
[9] Randhir T O and Ekness P 2013 Ecohyd. &Hydrobiol. 13 192
[10] Brix H 2003 1st Int. Sem. on The Use of Macrophytes for Wastewater Treatment Constructed Wetlands (Lisboa) p1-30
[11] Shlef O, Gross A and Rachmilevitch 2013 Wat.5 405
[12] Zhang D Q, Jinadasa K B S N, Gersberg R M, Liu Y, Tan S K and Ng W J 2015 J. Environ. Sci.30 30
[13] Tanner C C and Headley T R 2011 Ecol. Eng. 37 474
[14] Wang C Y, David J Sample and Bell C 2014 Sci. of the Tot. Environ.499 284
[15] NTEAP 2007 Schematic representation of vegetation riparian type RAMP gallery image http://www.ramp-alberta.org/ramp/gallery.aspx?galleryimage=1054 Upload January 20 2019.
[16] James WF, Barko JW and Butler MG 2005 Hydrobiol. 515 181
[17] Xu F, Yang ZF, Chen B and Zhao YW 2013 Ecol. Model. 252 267
[18] Hilt S, Gross EM, Hupfer M, Morschheiz H, Mahlmann J, Melzer A, Poltz J, Sandrock S, Scharf EM, Schneider S and van de Weyer K 2006 Limno. 36 155
[19] Amano K, Oishi T and Tokioka T 2008 World Environ. and Wat. Res. Cong. Ahupua’a ASCE libraryDOI: 10.1061/49076(316)271
[20] Jethwa, K B and Baijal S 2016 Role of plants in constructed wetlands (CWS): a review J. Chem. Pharma.Sci. 2 4
[21] Henny C and Meutia AA 2014 Proc. World Lake Conf. (Perugia)WLC15 26
[22] Kurniawan R and Henny C 2015 Proc. Limnol. Soc. Indonesia Annual Meeting (Bogor)MLI 375
[23] Kurniawan R and Henny C 2015 5th Int. Conf. JABODETABEK Forum (Bogor - Crestpen Press) 623
[24] Wang C, Zheng S, Wang P, Quan J 2014 Effects of vegetation on the removal of contaminants in aquatic environments: A review J. Hydro. 26 497
[25] Meutia A A and Satya A 2007 Limnotek. 15 (1) 19
[26] Meutia A A 2001a. Wat. Sci. & Technol. 44 499
[27] Meutia A A 2001b. Technical Report Research Center for limnology-Indonesian Institute of Sciences
[28] Chrismada T, Suryono T, Mardiati Y, Mulyana E 2017 Proc. World Lake Conf. (Bali) WLC 16 411
[29] Susanti E, Oktaviany D and Henny C 2012 Limnotek. 19 72
[30] Henny C, Suryono T, Kurniawan R, Rosidah, Sudiono BT 2014 Technical Report Research Center for Limnology-Indonesian Institute of Sciences
[31] Henny C, Kurniawan R and Rosidah 2019 Treatment of POME supernant using hybrid constructed wetland In press
[32] Kurniawan R and Henny C 2017 Proc. Limnol. Soc. Indonesia Annual Meeting (Bogor) MLI 4 97
[33] Henny C, Kurniawan R, Akhdiana I 2019 Int. Symp. on Biorevegetation and Bioremediation (Bogor - IOP Publishing)
[34] Henny C, Kurniawan R, Suryono T 2019 Int. Conf. on Ecology and Biodiversity Across Space and Time (Penang - IOP Publishing)
[35] Henny C and Gunawan 2012 Technical Report Research Center for limnology-Indonesian Institute of Sciences
[36] Raharjo S, Suprihatin, Indrasti N S, Riani E, Supriyadi and Hardanu W 2015 J. Man. Ling. 22 (2) 201
[37] Qomariyah S, Sobriyah, Koosdaryani and Muttaqien A Y 2017 J. Ris. Rek. Sip. Univ. Sebelas Maret 25
[38] Ambarsari H and Qisthi A 2017 J. Teknol. Lingkung. 18 (2) 148
[39] Sari E, Sari M, Awal R, Jumiati and Sundari A 2018 IOP Conf. Ser.: Earth Environ. Sci. 175 012096
[40] Handajani H, Widanarni, Budiardi T, Setiawati M and Sujono 2018 Omni-Aku. 14(2) 43
[41] Jampeetong A, Brix H and Kantawanichkul S 2012 Aquat. Bot. 97 10
[42] Toscano A, Marzo A, Milani M, Cirelli GL, Barbagallo S 2015. Comparison of removal efficiencies in Mediterranean pilot constructed wetlands vegetated with different plant species Ecol. Eng. 75 155
[43] Olguin EJ, Sanches-Galvan G, Francisco J Melo, Victor J Hernandez and Ricardo E Gonzalez-Portela 2017 Long-term assessment at field scale floating treatment wetlands for improvement of water quality and provision ecosystem services in a eutrophic urban pond Sci. of the Tot. Environ. 584-585 561
[44] Wang C Y, David J Sample, Susan D Day and Thomas J Grizzard 2015 Floating treatment wetland nutrient removal through vegetation harvest and observation from field study Ecol. Eng. 78 284
[45] Dou T, Troesch S, Petitjean A, Gabor P T and Esser D 2017 Proc. Environ. Sci. 37 535