Nutrients removal from integrated multi-trophic aquaculture (IMTA) water using waste stabilization ponds (WSP)

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Abstract. Nutrients enrichment due to waste from Keramba Jaring Apung (KJA) aquaculture is one of the main causes of eutrophication in Indonesian Lakes and Reservoirs. Integrated multi-trophic aquaculture (IMTA) is one of environmentally friendly aquaculture that currently being developed at the Research Center (RC) for Limnology - National Research and Innovation Agency (BRIN). This aquaculture would re-use its water, along with fish waste and leftover fish pellets, to grow Duckweed (Lemna sp.) in its ponds system as additional feed. However, due to closed water recirculation in IMTA ponds system, the water quality would eventually deteriorate which would be marked with high turbidity of organic solid waste and low dissolved oxygen (DO). This study aims to improve water quality from aquacultures activity, especially in nutrients (nitrogen and phosphorus) reduction, using a constructed wetland (CW) system. This system consists of waste stabilization ponds (WSP) and compartments of CW and adsorbent. During this initial stage, IMTA water was treated in the WSP for then observed for its improvements in the nutrients and other water quality parameters. This research was conducted from July to September 2019 in the Prototype Laboratory of RC for Limnology-BRIN. Parameters of DO, conductivity, pH, oxidation reduction potential (ORP), and salinity were observed using a calibrated water quality checker (WQC) Horriba®, while nutrients parameters in the form of N-NH₄, N-NO₂, N-NO₃, P-PO₄, and dissolved organic matters (DOM) were measured in the laboratory referring to the standard method of the American Public Health Association (APHA). Results showed that average values of turbidity and electrical conductivity parameters were reduced from 102 to 76 NTU and 0.21 to 0.14 mS/cm, respectively. Average nutrients reductions were also found from N-NO₂, N-NO₃ and P-PO₄ parameters of 85.5%, 44.3% and 37%, respectively. Significant changes were observed in parameters of DO and N-NH₄. DO was increased from 4.63 mg/L to 7.44 mg/L, while N-NH₄ were reduced for 81%. Even though the experiments were not conducted during low DO conditions of water from IMTA ponds, improvements from the vital water quality parameters after treatment in the WSP were observed.

Key words: waste stabilization ponds (wsp), water quality, nutrients, eutropication.

1. Introduction
Direct wastewater disposal of leftover feed and manures from floating net cages (KJA) aquaculture into water bodies is one of the main causes of the water quality degradation in Indonesian inland water ecosystems. Due to the high loading of nutrients, mainly nitrogen (N) and phosphorus (P) [1,2], which came from these aquacultures many Indonesian Lake statuses became eutrophic to hyper-eutrophic. Within National Priority Research Program for Lake Maninjau Rehabilitation, a constructed wetland
system (CW) was proposed for the water quality treatment for the KJA wastewater. CWs have been rapidly developed as alternative technological solutions in wastewater treatment [3-8]. The proposed wetland system consists of a waste stabilization pond (WSP), CW and adsorbent compartments. WSP’s main function is to separate solid waste of manures and fish feed residues from the water and to improve water quality while remaining nutrients and other pollutants in the dissolved phase would then be removed using CW and adsorbent compartments.

In this preliminary stage, a CW system was built in the prototype laboratory of Research Center (RC) for Limnology-Brin. The system was built to improve water quality from the existing integrated multi-trophic aquaculture (IMTA) system. Using the recycling concept, IMTA is environmentally friendly aquaculture. This closed water recirculation system would then re-use waste from main cultured aquatic species to fertilize aquatic plants as additional feed. Therefore the productivity within aquaculture ponds can then be increased, while its waste can be kept minimized. This aquaculture system has also been used to reduce problems in many open-waters [9]. However in this aquaculture system also intensive feedings were done to maximize yields. Excess of the high load of the organics and nutrients, similar to KJA, from this feeding activity, would eventually decrease ponds water quality [10]. The deterioration can be observed from low water dissolved oxygen (DO) to high turbidity due to manures and leftover feed. The low DO concentration in the water column could be attributed to the use of DO for the metabolism of microorganisms. While in the sediment, the decomposition process from the settled organic matter contributes to the anoxic condition in the ambient environment. The closed re-circulation system of aquaculture adopted within IMTA had intensified these problems. The re-circulated water would then accumulate even more organic matter within the bottom of the ponds that would speed up the decrease of the water quality conditions.

For this initial study’s effectiveness of WSP in improving water quality, especially to reduce nutrients, in IMTA water, was observed. WSP is widely used [11] due to low capital and operating costs, simplicity in operation and maintenance, and the ability to handle a wide range of organic and hydraulic loads. The different types of WSP could be used individually; however, the most efficient system consists of three stages in a series. An anaerobic pond for then followed by facultative ponds that are designed for organic matter removal. At the end of the series, a maturation pond is used for pathogen removal. These removal processes are not strict since some organic removal occurs in maturation ponds, while some pathogen removal might also happen in anaerobic and facultative ponds [12]. This system of WSP was also chosen because, in the tropical climate, the system would have high efficiency and would operate all year round.

2. Methods
The WSP system shown in Figure 1 was used to process two series of IMTA ponds in RC for Limnology National Research and Innovation Agency (BRIN). This IMTA aquaculture was being developed to maximize yields of Catfish (Clarias sp.). The water including its waste was then re-circulated in a series of ponds to fertilize Duckweed (Lemma sp.). Each series consisted of 4 interconnected ponds with only the first ponds were filled with 1000 catfish seeds, while other ponds were contained with lemma sp. The WSP system consisted of anaerobic, facultative and maturation ponds with dimension each of 1.5 x 1.5 x 3 m, 3 x 5 x 1.7 m, 3 x 7 x 0.7 m. While, hydraulic retention time (HRT) in each pond were 1-2 days in anaerobic ponds, and about a week each in facultative and maturation ponds. Observations were made in July-September 2019. After acclimatization for 2 weeks, observations were made twice a week (n=8) from August to September to obtain water quality parameters. The parameters observed were pH, turbidity, DO, oxidation and reduction potential (ORP), conductivity, and temperature using water quality checkers Horriba®. While for nutrients parameters of N-NH₄, N-NO₂, N-NO₃, P-PO₄ and dissolved organic matter (DOM) samples were taken only once a week (n=4) for further analysis in the hydrochemistry laboratory. The analysis was conducted referring to the standard method published by American Public Health Association [13]. The results obtained were then analysed statistically using SPSS 13®. To determine the significance
difference of the water quality parameters before and after treatment using WSP, comparison for normally distributed data paired t-test were used, while which were not tested using the Wilcoxon test.

![Figure 1. IMTA and WSP system in Prototype Laboratory RC for Limnology BRIN.]

3. Results and Discussion
Figures 2 to 5 are the results from average values and standard error measurement on temperature, pH, conductivity, and turbidity. Temperature ranges from 25.9°C to 30.5°C with an average of 27.9°C. These values were obtained because the water measurements were generally carried out from morning until afternoon. During these observations, photosynthesis by phytoplankton occurs to consume acidic CO₂ in the water column [14]. Thus, water pH at facultative and maturation ponds were tends to be slightly more alkaline with an average of 6.78 and 7.01, compared to the anaerobic pond with an average of 6.6. Overall there was a decrease by 34.5% in the average conductivity values in the WSP. The photosynthesis process would also synthesise the new biomass of phytoplankton. As water column productivity increased, the growth from microorganisms would then consume ions from the treated IMTA water [15,16,17]. This biomass production was also related to the dynamics of turbidity in the WSP pond. Overall, water turbidity from the inlet of WSP was successfully reduced. The decrease in turbidity was mainly contributed by solid-liquid waste separation in the anaerobic pond for an average of 81%. However, biomass growths within facultative pond would then slightly increase the average turbidity with an average of 89.5 NTU. Intense sunlight penetration removing pathogen and the continuation of the dead biomass settling in the maturation pond made the net overall WSP turbidity decrease by 26%.

Results of ORP and DO were shown in Figures 6 and 7. An intense photosynthetic process occurred during the measurements, resulting in an increase of DO especially in both facultative and maturation ponds. The final increase within the WSP was found significant, Z=-2.521, P<0.05, for an average of 7.44 mg/L in maturation pond compared to the average inlet water of 4.63 mg/L. These relatively high DO indicate the good water quality conditions from IMTA water during observations. Because, during the worst conditions, IMTA water would have DO values close to 0 mg/L. Meanwhile, the oxygen produced from this process was also steadily increased the ORP values along with these treatment ponds. There was an overall increase of 35.5% of ORP in maturation pond compare to the inlet water.
Nutrients, mainly of N and P, in the form of ammonia nitrate and nitrite and phosphate were all found decreased in this study, while the DOM was found relatively constant (Figure 7-10). The highest average of nutrient values were observed in the inlet water for: 0.168 mg/L, 0.142 mg/L, 0.984 mg/L, 0.378 mg/L for N-NH₄, N-NO₂, N-NO₃, P-PO₄ respectively. In the maturation pond, as an outlet for the WSP system, the lowest nutrient contents were observed with an overall removal efficiency of
81%, 85.51%, 44.33%, and 36.90% respectively for the parameters of \(N-\text{NH}_4\), \(N-\text{NO}_2\), \(N-\text{NO}_3\), \(P-\text{PO}_4\). This removal was found significant for \(N-\text{NH}_4\) \(t(3)\), \(p<0.05\).

![Figure 8](image8.png)  
**Figure 8.** Mean values of \(N-\text{NH}_4\) in WSP.

![Figure 9](image9.png)  
**Figure 9.** Mean values of \(N-\text{NO}_2\) in WSP.

![Figure 10](image10.png)  
**Figure 10.** Mean values of \(N-\text{NO}_3\) in WSP.

![Figure 11](image11.png)  
**Figure 11.** Mean values of \(P-\text{PO}_4\) in WSP.

![Figure 12](image12.png)  
**Figure 12.** Mean values of DOM in WSP.
In the WSP system, nutrients are used for the productivity of ponds, for then its fractions would be removed through settling and volatilization process. This prototype of WSP was quite effective in reducing nutrient contents. The differences of nutrient reductions were observed among different types and conditions of WSP [18–21]. With a smaller size, this prototype of WSP would be more susceptible to external influences such as debris, rain, etc. Adding to that, smaller efficiency compare to some WSP’s [22–23] could be attributed to the initial nutrient concentrations in the water that was already relatively low and DO were high. Thus, the overall observations were not conducted in the worst condition with DO close to 0 mg/L and high turbidity from IMTA particulates organic waste. DOM average values during treatment were relatively unchanged. These organic matters came from fractions of IMTA waste in form of faeces and leftover catfish food. Instead of the dissolved phase, the removal of organic matters in the anaerobic pond was mainly attributed to the particulate phase. There was a slight decrease in the average DOM in the facultative from the anaerobic pond of 158.89 mg/L to 142.76 mg/L. This decrease could be derived from DOM that was used in pond productivity for the synthesis of new biomass within the facultative pond. Overall the outlet water from the WSP system has met the qualifications for the nutrients content required by the Indonesian government for aquaculture [24].

4. Conclusion
Observed prototype WSP within CW system applied on IMTA aquaculture water treatment performed efficiently to increase the water quality and to reduce nutrients. The outlet water from WSP could meet nutrients regulation from National regulation of water use for aquaculture.

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