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Phytoremediation of African catfish waste using aquatic plant species in peat water

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ABSTRACT

Aquatic plants are adaptive living on the gradient of acidity of peat waters in Palangka Raya city, with their potential role in remediating city wastewater. This research is aimed to study the ability of several aquatic plant species to remediate organic wastewater on a laboratory scale. The treatment was done from July to September 2020 in the field laboratory, greenhouse in Palangka Raya, Central Kalimantan. We compared the phytoremediation abilities of aquatic plant species, i.e. water hyacinth (*Eichornia crassipes*), pickerelweed (*Monochoria vaginalis (*Burm. F*) Presi*), water spinach (*Ipomoea aquatica*), water primrose (*Ludwigia ascedences*), water lettuce (*Pistia stratiotes*), giant Salvinia (*Salvinia molesta*), and hornwort (*Ceratophyllum demersum*) on the wastewater of African catfish (*Clarias gariepinus*) by measuring coverage as an indicator of their growth and absorption ability. Physicochemical parameters measured were water level, sunlight intensity, water temperature, electrical conductivity, potential oxidation-reduction, pH, dissolved oxygen, phosphate, nitrate, and ammonia. Results showed that of seven species tested for their phytoremediation abilities on wastewater, giant Salvinia was among the highest reducing total organic matter by about 95%. The highest coverage was water lettuce by 92%, followed by giant Salvinia (79%) and water hyacinth (78%). However, phosphate and ammonia had a negative value of the relative absorption for all aquatic plant species, suggesting a surplus in concentration during incubation. In this case, absorption for phosphate and ammonia is detected from a median of the lowest concentration on each species (n = 4). Water hyacinth and giant Salvinia were the highest absorbing for respectively phosphate and ammonia. Nitrate was absorbed by 100% of all species, except hornwort of 88%. The best absorption of nitrate was by water lettuce. So, it can be concluded that giant Salvinia is the best at absorbing organic waste, followed by water hyacinth; and the best growing by coverage is water lettuce.

Introduction

Phytoremediation is a process of applying aquatic plants to extract, absorb, and detoxify contaminants in the water column, as mentioned by Parmar and Singh (2015), and is also known as botanical remediation or green remediation (Ergonul *et al*, 2017). The ability of aquatic plants to reduce organic and inorganic liquid waste is well-known and widely studied and applied in the context of phytoremediation (Effendi *et al*., 2015; Sytar *et al*., 2015; Raissa and Tangahu, 2017; Akbar & Khairunnisa, 2024; Welhelmus Djo *et al*., 2017; Astuti and Indriatmoko, 2018; Novita *et al*., 2019).

Organic waste from catfish farming can be reduced by phytoremediation using water spinach (*Ipomoea aquatica*) and pakcoy (*Brassica rapa chinensis*) in a technique or circulation system (Effendi *et al*., 2015). According to Novita *et al*. (2019) water hyacinth (*Eichornia crassipes*), giant salvinia (*Salvinia molesta*), and water lettuce (*Pistia* sp.) can reduce the organic waste of tofu processing, especially for the parameter of biological oxygen demand, chemical oxygen demand, nitrogen, total suspended solids, and

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turbidity above which are reaching of 55%. The water lettuce (*Pistia stratiotes*) according to Raissa and Tangahu (2017) can reduce laundry waste, especially biological oxygen demand, chemical oxygen demand, and phosphate levels above 95%. Water hyacinth can reduce chemical oxygen demand, copper, and chromium levels ranging from 40% to 70% of the laboratory waste (Welhelmus Djo *et al*., 2017). According to Imtiyaz and Rachmadiarti (2020), water primrose (*Ludwigia ascedences*) can reduce the concentration of *Linear Alkylbenzene Sulfonate* in wastewater, as well as Cadmium of the polluted waters and swine manure wastewater as reported respectively by Rosyada and Purnomo (2018) and Xu *et al*. (2020).

The present study aimed mainly to compare the phytoremediation abilities of several species of aquatic plants in organic wastewater. The wastewater used as media is African catfish (*Clarias gariepinus*) wastewater reared in the peat water. The aquatic plant species are water hyacinth (*Eichornia crassipes*), heartshape false pickerel weed (*Monochoria vaginalis (*Burm. F*) Presi*), water spinach (*Ipomoea aquatica*), water primrose (*Ludwigia ascedences*), water lettuce (*Pistia stratiotes*), giant salvinia (*Salvinia molesta*), and hornwort (*Ceratophyllum demersum*). These aquatic plant species have been growing in natural and artificial waters around Palangka Raya City which is mostly situated on the peat lands, with a dark brown color of peat water with a pH between most of between 4 and 6.

The hornwort is a type of submerged aquatic plant, while the other five species are a type of free-floating aquatic macrophyte, except pickerel weed which is semi-aquatic weed (Athira *et al*., 2019). The pickerel weed belongs to the family pontederiaeece and consists of a widespread perennial or annual aquatic, floating herb (Nair, 2014). This species is an aquatic plant, that normally grows well in rice flooded (waterlogged) fields (FAO, 2020). According to Hariyadi (2020), heart-shaped false pickerelweed has the ability as a phytoremediator for chlorine in wastewater. The hornwort, according to Beheary *et al.* (2019), is effective in removing Tilapia aquaculture wastewater.

This study is considered important in studying the absorption ability of several aquatic plant species for the organic waste of African catfish in peat water. Some people in Central Kalimantan are rearing African catfish in the peatland. The remediation activity of such aquatic plant species in peat water has been rarely known under laboratory treatment. As mentioned above, these species have been adaptive living in the gradient of acidity of peat waters.

Materials and Methods

Location and time of research

The research was carried out at the researcher's field laboratory, with the address of Jalan Yos Sudarso V No. 107 Palangka Raya, Central Kalimantan. The treatment was done from July to September 2020 including collection of aquatic plants on the waters and construction of the greenhouse.

Experimental design and variables

The design of the experiment is by incubating 7 species of aquatic plants with 1 control in the basin or container with wastewater. The wastewater of African catfish reared in peat water was used as media. The control was no aquatic plants (only wastewater). Sampling was done 4 times with an interval of 15 days. The rounding mouth plastic basin with a capacity of 30 liters, filled with about 20 liters of wastewater was used for each experimental unit. The wastewater was homogenized before being distributed into each basin. To assess the ability of aquatic plant species to remediate wastewater, we measured the coverage (Cov) of each tested aquatic plant and main chemical parameters, such as phosphate (PO_4), nitrate (NO_3), ammonia (NH_3), and total organic matter (TOM). The supporting physicochemical parameters that were also measured in situ were water temperature (WT), electrical conductivity (EC), oxidation-reduction potential (ORP), pH, and dissolved oxygen (DO). Phosphate, nitrate, ammonia, and total organic matter were analyzed in the laboratory of Aquatic Resources Management, University of Palangka Raya.

Treatment steps

The preparation of the experiment house was the first step. It was a greenhouse where plastic basins as treatment units were arranged in such a way. The second step was the collection of aquatic macrophytes as the tested plant. Observation of aquatic plants was done to investigate the water's location of the natural growth of such species.

The collection of each aquatic plant species in the field was carried out directly with constructed hooks and nets (Figure 1A). Each aquatic plant species was collected from ditches and canals in Palangka Raya City. The amount of each aquatic plant taken was about 1 bucket of 10-liter capacity with a small amount of water, then put in a plastic bag. In the laboratory, all species were gently washed, especially their roots with clean water (borehole water) to

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remove adhering mud, then placed in a 30-liter capacity basin, and let for about 2 days to make them slightly adapted to the new environment.

In the third step, before placing each tested aquatic plant species all of the basins were already filled with wastewater amount of 20 liters. For each aquatic plant species, their biomass must first be equated or homogenized. The homogenization or equalization of biomass of each aquatic plant species was done because their size was naturally different. It was carried out by weighing using the measuring device which is designed to adopt the water replacement principle (Figure 1C). For equalization of biomass, each aquatic plant species was first drained, removing water for about 1 hour by placing it on the screening tool (sieve-like) with a dimension of 2 × 1 m that is made of wire mesh (green color) with a mesh-size of 1 cm^2 (Figure 1B). After that sequentially aquatic plant species were weighed, and immediately put into each plastic basin that was already prepared. Since the biomass of each aquatic plant species has been equated, the area covered by each species on the basin was different considering their natural size. The initial biomass of aquatic plants wasn't measured, instead, we just estimated its coverage. Increasing its coverage means an increase in its biomass. Measuring each aquatic plant biomass for every sampling is difficult owing to potentially disturbing their growing in the basin. So the growth of aquatic plants was estimated from their coverage. The initial covered area of each aquatic plant was measured by taking an image vertically from each basin of the species, then calculated and estimated in such a way using the SketchUp 13 (ver. 13) computer program. Similarly, the coverage area of each species on the sampling was also estimated with the same technique.

After all the subject aquatic plants were put into each basin which had already been filled with 20 liters of catfish wastewater. Waste water was homogenized before being distributed to each basin. The initial physicochemical parameters of wastewater were measured consisting of water level in the basin (WL), sunlight intensity (Chy), water temperature (WT), electrical conductivity (EC), oxidation-reduction potential (ORP), degree of acidity (pH), dissolved oxygen (DO), phosphate (PO_4), nitrate (NO_3), ammonia (NH_3), and total organic matter (TOM). Simultaneously with physicochemical parameters, an estimation of aquatic plant coverage (Cov) was carried out. After the initial measurement of physicochemical parameters and coverage, the incubation of aquatic plants on the wastewater was started. Sampling was carried out periodically for 4 times.

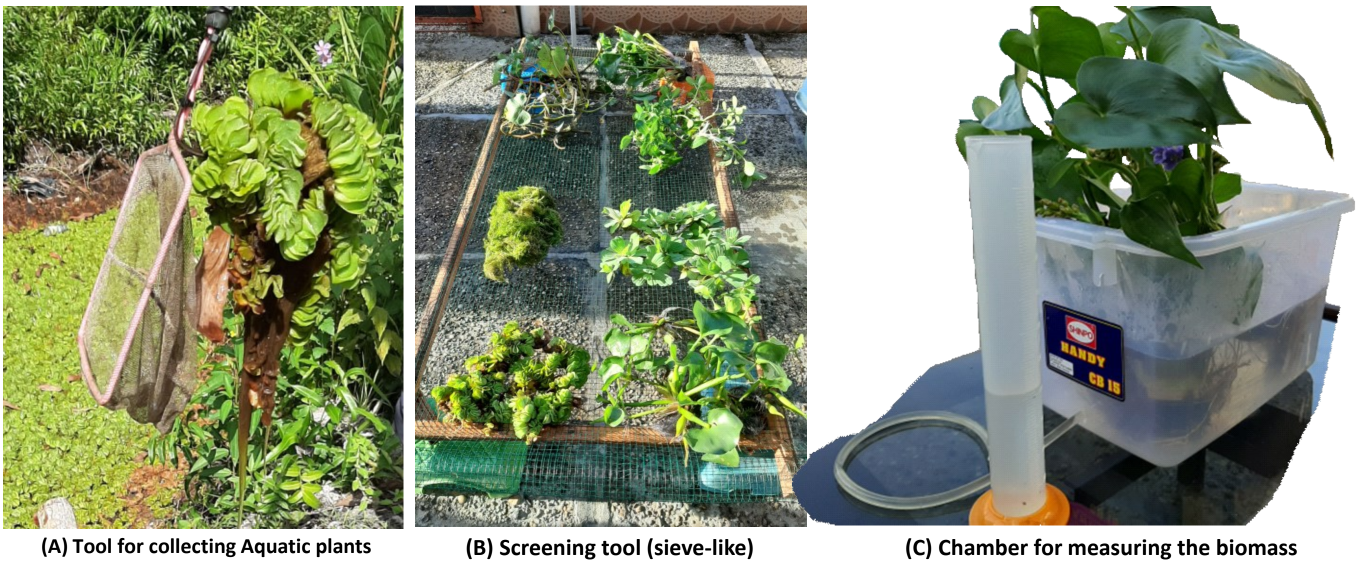

Figure 1. (A) the tool (net is attached metal hook) for taking aquatic plants on the waters, (B) the aquatic plant screening tool (sieve-like) made from a wire screen, mesh-size 1 cm^2 with wooden frame, and (C) the chamber for equalization of biomass of aquatic plants with the water replacement principle, a simple tool made of plastic basin (15 liters capacity) and volumetric flask connecting with 10 mm hose.

Physico-chemical parameter measurement

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Measurement of water level (WL) on the basin was using scale tape attached to PVC pipe. Sunlight intensity was measured with a light meter (Lutron, LX-103) on the canopy surface of each aquatic plant in each experimental unit (basin). Water temperature, EC, ORP, and pH were measured in situ in each experimental unit with the Horiba Laqua Act, pH/ORP/Cond Meter D-74, Japan as well as DO using Horiba, DO meter OM-12, Japan. As for PO_4, NO_3, and NH_3, the water samples of each experimental unit were analyzed respectively using the Hanna Instrument test kits made in the USA, HI 96713C phosphate low range ISM (ascorbic acid method), HI 96728C Nitrate ISM (cadmium reduction method), and HI 700 Ammonia Low Range (Nessler method). Meanwhile, total organic matter was analyzed by using the titration (titrimetry) method with the potassium permanganate (Indonesian National Standard, SNI 06-6989.22-2004). Aquatic plant coverage in each experimental unit was analyzed by taking photos or images of their coverage vertically. The image was analyzed with the SketchUp 2013 computer program, and the surface area of the basin covered by the aquatic plant's canopy was calculated and converted to real-scale units in the field. As a reference to the real scale, the diameter of the basin surface was manually measured to calculate the real surface area as the scale conversion unit in cm.

Relative absorbtion calculation

Calculation of relative absorption was done according to Muljadi (2009) as follows,

$$Relative\ absorbtion\ (\%) = \frac{intial\ concentration - final\ concentration}{initial\ concentration} \times 100$$

The return value of the relative absorption can be positive (+) or negative (-). The positive (+) indicates a reduction in concentration from the initial, while the negative (-) one means an increase in concentration.

Data analysis

Data of physicochemical parameters and coverage were descriptively analyzed for maximum, minimum, mean, or median. Visualization was done with line and boxplot graphs.

The relationship among parameters was revealed by their brief tendency with principal component analysis (PCA) and verified by Spearman's multiple correlations (Spearman Rank Correlation, rho). Statistical analysis and visual representation (drawing graphs) were analyzed and drawn with the R: A language and environment for statistical computing (R Core Team, 2020), and an additional package, Hmisc (Harrell *et al.*, 2020).

Results

Phytoremediation of several aquatic plant species in the present study has been considered essential in improving the water quality of waste of African catfish (*Clarias gariepinus*) cultured in peat water. The effort to find aquatic plant species that are adaptive and maximal to absorb organic catfish waste directly without pre-treatment is useful for purifying wastewater. Even if the wastewater is disposed directly into the water environment, by existing aquatic plants there, they are possible to reduce organic pollution entering the waters and drainage in the city, town, or village. This phytoremediation could also be the ability of aquatic plant species to absorb inorganic compounds decaying from the wastewater of African catfish under controlled conditions in the peat water. The elaboration of present results includes a brief description of the aquatic plant species applied, the absorption ability of aquatic plant species, and a brief overview of water quality parameters in their natural habitat.

The seven species of aquatic plants applied in this experiment were water hyacinth, coding as EG, and then EL for pickerel weed, KG for water spinach, TD for water primrose, KA for water lettuce, KM for giant Salvinia, and CER for hornwort. Among seven species, five are categorized as floating aquatic plants whose stems and leaves are in the atmosphere, and whose root is submerged in water. The Pickerelweed stems and leaves are in the atmosphere, but the root is submerged in water and mud. The hornwort is a submerged plant which is all of its parts (stems and roots) lying in the water column.

1. Water quality parameters

The data of physicochemical parameters and coverage of aquatic plants in this study are shown in Table 1. The concentrations and values of physical and chemical parameters of water quality comprising water temperature, EC, ORP, pH, DO, PO_4, NO_3, NH_3, and TOM during the treatment period were observed and varied in each basin (treatment unit) of plant species water (EG, EL, KG, TD, KA, KM, CER) as well as control treatment (K) and peat water (AG).

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Table 1. The data of physicochemical parameters and coverage of aquatic plants.

Aquatic Plant Code	Sampling	Light (Lux)	WL (cm)	WT (°C)	EC (µS/cm)	ORP (mV)	pH	DO (mg/l)	PO_4 (mg/l)	NO_3 (mg/l)	NH_3 (mg/l)	TOM (mg/l)	Cov (%)
EG	1	654	19	28.3	190	4	7.7	0.54	5.6	44.64	0.24	1395.2	35
EG	2	520	15.8	27.2	31.6	16	6.54	0.75	37.8	252.51	10.1	252.8	75
EG	3	820	12	27.7	22.4	134	4.49	2.97	46.2	8.4	3.4	821.6	90
EG	4	930	6.5	26.7	6.8	169	3.83	3.1	8.8	0	6.3	213.44	115
EL	1	654	19	28.3	190	4	7.7	0.54	5.6	44.64	0.24	1395.2	35
EL	2	520	15.7	27.2	28.9	9	7.11	1.14	35.2	88.6	7.04	783.68	65
EL	3	820	12.5	27.8	25.1	77	5.54	1.34	45.2	36.8	6.3	985.92	73
EL	4	930	7.5	26.9	18.2	6	6.69	0.81	58.8	0	11.8	103.48	78
KG	1	654	19	28.3	190	4	7.7	0.54	5.6	44.64	0.24	1395.2	15
KG	2	520	16.3	27.3	40.5	3	7.01	0.81	54	159.48	4.86	935.36	50
KG	3	820	11.5	27.9	10.22	58	5.63	0.86	49.4	2	6.7	12.64	85
KG	4	930	4	27.3	15.32	194	3.42	2.77	50.8	0	15.7	350.72	125
TD	1	654	19	28.3	190	4	7.7	0.54	5.6	44.64	0.24	1395.2	20
TD	2	520	16.5	27.2	47.3	-26	7.21	1.18	47	97.46	9.23	846.88	20
TD	3	820	13.3	27.9	30.4	-5	6.85	1.48	44.6	31.6	5	353.92	15
TD	4	930	10	26.7	37.9	0	6.95	0.88	12.4	0	9.3	187.04	10
KA	1	654	19	28.3	190	4	7.7	0.54	5.6	44.64	0.24	1395.2	50
KA	2	520	15.6	27.7	29.3	29.3	6.14	0.56	42.6	261.37	7.29	290.72	98
KA	3	820	13.5	28.6	9.7	152	4.17	2.27	42.8	0	4.7	1074.4	110
KA	4	930	10	27.6	9.3	186	3.57	1.92	40.2	0	4.1	75.84	110
KM	1	654	19	28.3	190	4	7.7	0.54	5.6	44.64	0.24	1395.2	45
KM	2	520	17.1	27.6	36.5	61	5.75	1.35	43.8	289.84	2.43	303.36	70
KM	3	820	14	28.3	30.8	121	4.74	1.54	49.8	10.8	7.1	505.6	95
KM	4	930	11.2	27.8	29.2	109	4.87	2.77	50.8	0	5.9	227.52	105
CER	1	654	19	28.3	190	4	7.7	0.54	5.6	44.64	0.24	1395.2	30
CER	2	520	16.5	27.3	47	-49	7.61	1.18	39.2	26.58	6.31	126.4	35
CER	3	820	13.5	28.7	31.1	-20	7.12	2.25	55.8	38.4	6.7	973.28	45
CER	4	930	9.5	27.1	37.7	-28	7.28	2.25	57.6	5.2	4.3	278.08	15
K	1	654	19	28.3	190	4	7.7	0.54	5.6	44.64	0.24	1395.2	0
K	2	520	16.5	27.5	44.9	-51	7.64	1.76	43.6	168.34	6.8	1390.4	0
K	3	820	13.5	28.3	26.6	-31	7.32	2.08	59.0	18	2.1	758.4	0
K	4	930	10	27.8	29.2	-77	8.08	3.92	53.6	0	2.8	202.24	0
AG	1	654	19	28.3	4.61	172	3.83	5.75	5.6	28.29	0.24	12.87	0
AG	2	520	16.5	28.3	4.61	172	3.83	5.75	4.14	28.29	0.24	12.64	0
AG	3	820	15	28.3	4.57	170	3.86	4.83	5.8	0	2.6	50.56	0
AG	4	930	11.4	27.7	5.4	173	3.78	4.51	7	0	5.5	37.92	0

Note : Light: sunlight intensity, WL: water level, WT: water temperature, EC: electrical conductivity, ORP: oxidation-reduction potential, pH, DO: dissolved oxygen, PO_4: phosphate, NO_3: nitrate, NH_3: ammonia, TOM: total organic matter, and Cov: coverage of aquatic plant species, EG: water hyacinth (*Eichhornia crassipes*), EL: pickerelweed (*Monochoria vaginalis*), KA: water spinach (*Ipomoea aquatica*), TD: water primrose (*Ludwigia ascedences*), KA: water lettuce (*Pistia stratiotes*), KA: giant Salvinia (*Salvinia molesta*) and CER: hornwort (*Ceratophyllum demersum*) in the basin (treatment unit). K: Control and AG: pure peat water, the experimental unit as control. Negative standard reduction potential (ORP) means that the tendency to get reduced is less than hydrogen or more ease to get oxidized than hydrogen.

Physico-chemical parameters, e.i. water level, WL, water temperature, WT, EC, ORP, pH, DO, PO_4, NO_3, NH_3, and TOM varied during the experimental period as shown in Figure 2 and Figure 3. Water volume as expressed by WL was decreasing during the experiment because evaporation occurred for all experimental units. The water temperature on the other hand tended to fluctuate at the same time as shown in Figure 2. The electrical conductivity (EC) of most of the experimental units showed the same trend. It was a sharp decline from sampling 1 to sampling 2, and then relatively flatted until sampling 4, except for only peat water (AG), as the second control which was likely flat from sampling 1 to 4.

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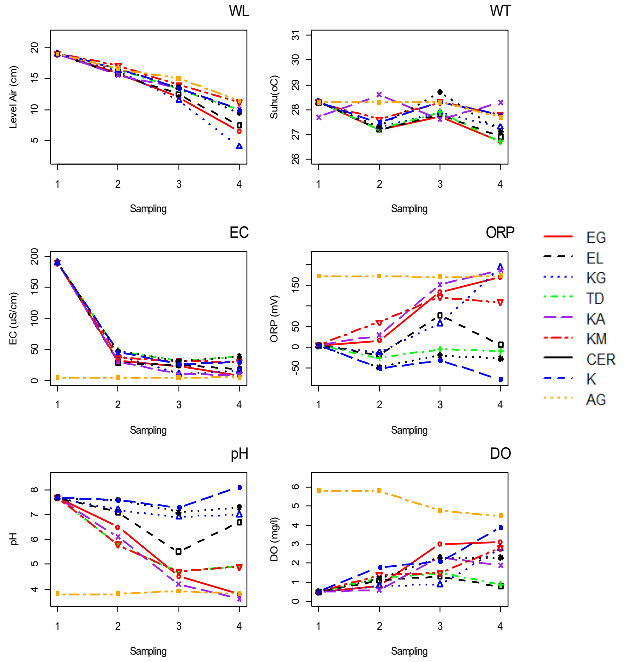

Figure 2. Trends of physicochemical parameters: Water temperature (WT), EC: electrical conductivity, ORP: oxidation-reduction potential, pH, and DO: dissolved oxygen during the experiment 4 times sampling for each experimental unit, namely EG, EL, KA, TD, KA, KA, CER and control (K) and peat water (AG), cf. Table 1. The x-axis is the sampling time.

Oxidation-reduction potential (ORP) showed the different trends in each experimental unit (aquatic plant species), as shown in Figure 2. It can be seen that for EG, KG, KA, and KM, the ORP values increased from the beginning (Sampling 1) to the end (sampling 4). Whereas in TD and EL, ORP tended to flat, while CER and K exhibited to decrease from Sampling 3 to Sampling 4. On the other hand, for peat water (AG) as a control treatment, ORP did not fluctuate during the experiment at almost all experimental units. The pH showed the same pattern, that is decreasing from Sampling 1 to Sampling 3, and increasing to Sampling 4 in all experimental units, except EG and KA which continued to decrease until Sampling 4. Dissolved oxygen (DO) increased from Sampling 1 to Sampling 4, especially for EG, EL, KG, KM, and K, otherwise, KA, TD, and CER decreased from Sampling 3 to Sampling 4.

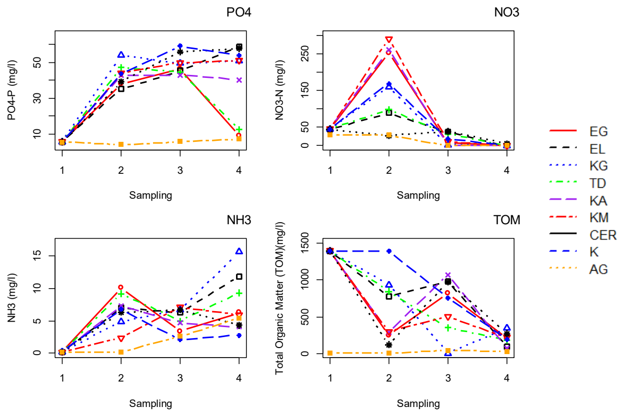

Figure 3. Trends of physicochemical parameters: PO_4: phosphate, NO_3: nitrate, NH_3: ammonia and TOM: total organic matter during the experiment 4 times sampling for each experimental unit, namely EG, EL, KA, TD, KA, KA, CER and control (K) and peat water (AG), cf. Table 1. The x-axis is the sampling time.

Phosphate (PO_4) trends in Figure 3 showed the same pattern for EL, KG, KA, KM, and K, increasing from Sampling 1 to Sampling 3, then tending to plate from Sampling 3 to Sampling 4. Meanwhile, each EG and TD increased from Sampling 1 to Sampling 3, then decreased to Sampling 4. Nitrate (NO_3) concentration at all experimental units of EG, EL, KG, TD, KA, KM, CER, and K showed almost the same pattern, which increased from Sampling 1 to Sampling 2, and then decreased to Sampling 4. Ammonia (NH_3) concentration for EG, KG, TD, CER, and K tended to increase from Sampling 1 to Sampling 4, while EL and KA at the same moment increased only from Sampling 1 to Sampling 2, then decreased toward Sampling 4. However, AG seemed to increase from Sampling 2 to Sampling 4. For total organic matter (TOM) as shown in Figure 3, especially EG, EL, KA, KM, and CER decreased by fluctuation from Sampling 1 to Sampling 4, although KG seemed to decrease sharply. Control (K) slightly decreased, afterward increased again from Sampling 3 to Sampling 4.

2. Coverage and absorption of aquatic plants

Most of the aquatic plant species applied could absorb African catfish waste as indicated by increasing their coverage over time. The aerial view coverage of each species of aquatic plants on the basin from sampling 1 to 4 is shown in Figure 4. Coverage of each species was different exhibited by

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its mean of 4 sampling time. The highest coverage was water lettuce (KA) about 92%. It was followed respectively by giant Salvinia (KM),79%, water hyacinth (EG), 78%, water spinach (KG), 68%, pickerelweed (EL), 62%, hornwort (CER), 31%, and water primrose (TD), 16%.

The increasing of coverage as the growing trend was seen for EG, KG, KA, and KM from sampling 1 to 4, as well as EL was relatively increasing. CER coverage increased only from sampling 1 to sampling 3, then decreased to sampling 4. In turn, TD tended to decrease from sampling 1 to sampling 4 (Figure 4).

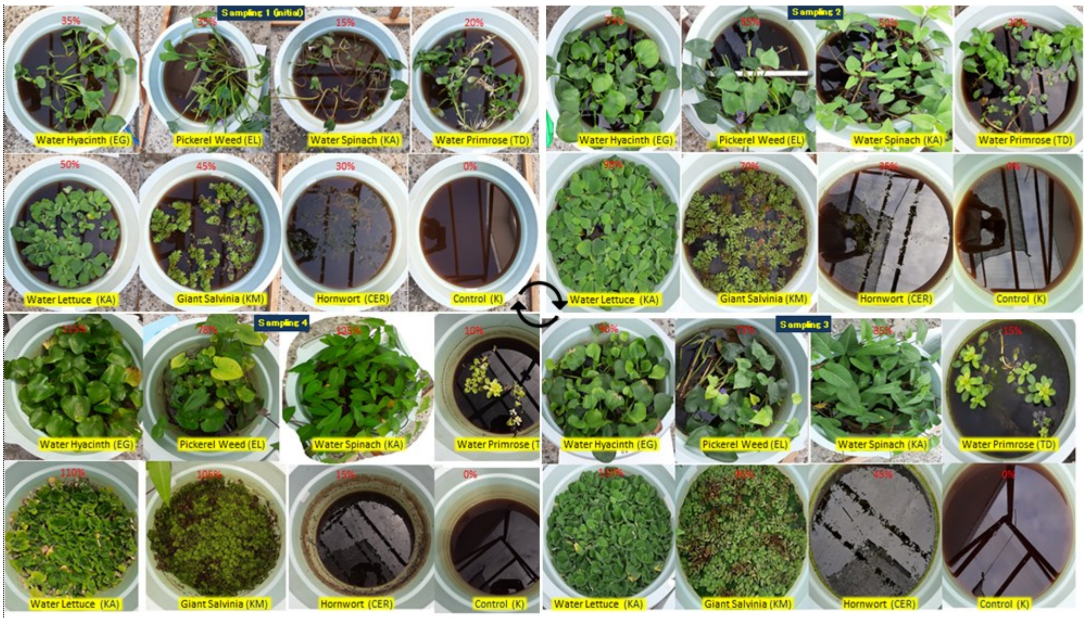

Figure 4. Aerial viewed coverage (%) of each species of aquatic plants, cf. Fig. 1, clockwise: Sampling 1 (initial), Sampling 2, Sampling 3, and Sampling 4. Increment of coverage of some treated species aquatic plant by time.

As shown in Figure 5, water hyacinth (EG), water spinach (KG), water lettuce (KA), and giant Salvinia (KM) seemed to increase their growth beyond the 4th sampling time, if only was not limited by the basin opening space. Pickerelweed (EL) on the other hand revealed slowly growing in comparison to the previous four species which are all free-floating aquatic plants. Pickerel weed has the same family, Pontederiaceae, as water hyacinth, it is not truly a free-floating macrophyte. In the natural habitat, pickerel weed root almost attaches to the muddy bottom of the waters. On present treatment, pickerel weed was forced to absorb nutrients directly from water. So, this species might not be growing well in this situation in comparison to water hyacinths even if they are same family.

Water primrose (TD), in many water bodies in Palangka Raya, is a free-floating macrophyte and is sometimes seen to grow well on city ditches. However, its coverage was the lowest among treated species in this research. This species presumably could not grow with concentrated wastewater in the treatment compared with it living in natural conditions.

Chemical parameters used as indicators of the ability of each aquatic plant species to remedy wastewater of African catfish cultured in peat water were TOM, PO_4, NO_3, and NH_3. The relative absorption of these parameters is shown in Table 2, exhibiting different values during the incubation. All PO_4 and NH_3 showed an increase or surplus in concentration during the incubation days, in which the relative absorption is marked by a negative (-) value. On the other hand, all of the species for NO_3 and TOM decreased in concentration which has a positive (+) value of relative absorption (Table 2). The organic matter absorption of all species of aquatic plants, as pointed out by TOM was above 70%, where the highest was in KA by 95%. In contrast, the lowest TOM absorption of 75% was found in KG. For NO_3, the uptake of almost all aquatic plant species was 100%, except for only the CER which was 88%.

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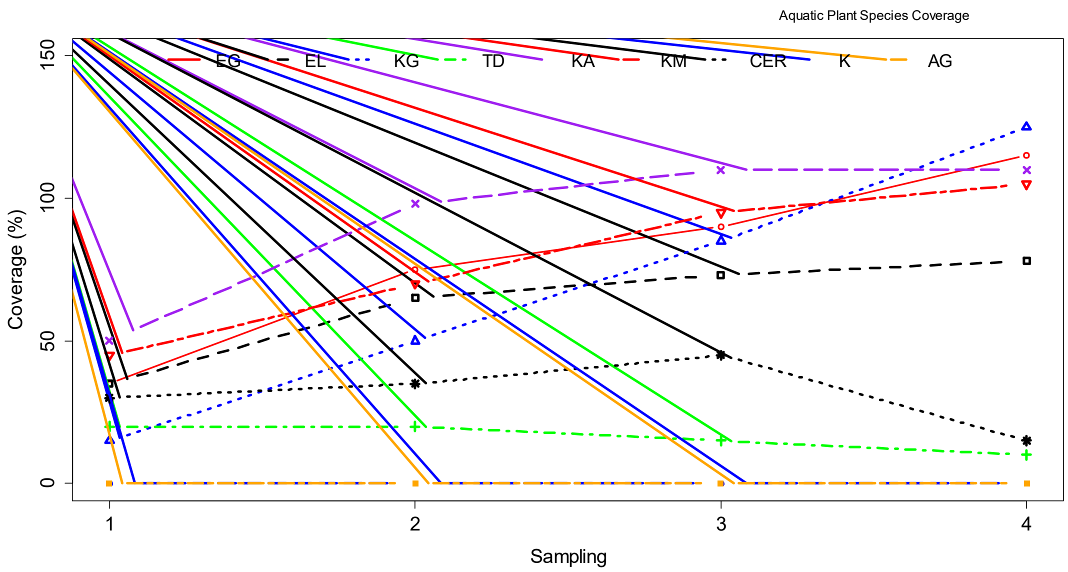

Figure 5. Coverage as indicator growing of aquatic plant species, EG, EL, KA, TD, KA, KA, CER and control (K) and peat water (AG), cf. Table 1. The x-axis is the sampling time.

The decreasing concentration of TOM over time incubation suggested that decaying organic matters occurred. It was converted into inorganic matter such as phosphate, nitrate, and ammonia. In the current situation, NO_3, PO_4, and NH_3 were potentially absorbed by aquatic plants. This was indicated by an increase in their coverage. Unfortunately, it could not be detected directly from the existing concentration of NO_3, PO_4, and NH_3, because there was a gain in concentration during the incubation time. In another sense, there a surplus of concentration occurred.

All of the relative absorption species on PO_4 were surplus (-) as well as NH_3. The lowest percentage of PO_4 surplus was found in EG at about -57% and the highest was in EL at -950%. For NO_3 on the other hand, all aquatic plant species had 100% absorption (+), except hornwort by 88%. For NH_3 the highest surplus of relative absorption was found in, water spinach, KG, by -6442%, while the lowest one was found in hornwort, CER by -1692%. All other species for surplus are presented in Table 2.

Phosphate and ammonia have a negative value of relative absorption for all aquatic plant species. In this case, absorption for phosphate and ammonia can be detected from its lowest concentration.

Comparing phytoremediation of aquatic plant species by their coverage (Cov) and relative absorption on chemical parameters, especially total organic matter (TOM), phosphate (PO_4), nitrate (NO_3), and ammonia (NH_3) are shown in Figure 6.

As mentioned earlier, the highest coverage was water lettuce (KA), followed by giant Salvinia (KM) and water hyacinth (EG) (Figure 6). However, by concentration, KM had the lowest TOM concentration, median of 404.5 mg/l, followed by EG, 537.2 mg/l. Whereas, KA was the second-highest TOM concentration (682.6 mg/l) after Pickerelweed (EL). This indicated that in giant Salvinia and water hyacinth basins, more organic matter decomposed than others. This was supported by the biplot principal component analysis (PCA) visualization in Figure 7, that the tendency for a negative relationship between total organics (TOM) and coverage (Cov) on axis 1 (PC1) contributes around 51% of the variance, even though the correlation did not significant (the Spearman's rho = -0.34, p = 0.059). For phosphate (PO_4), the lowest concentration was found in the EG (median = 23.3 mg/l), while the lowest concentration of nitrate (NO_3) was in KA (median = 22.3 mg/l). The concentration of ammonia (NH_3), KM was the lowest by a median of 4.16 mg/l. Whereas, KA and EG were second and third low concentrations of NH_3 respectively 4.40 mg/l and 4.85 mg/l. The visual comparison of species by percentage coverage and concentration of phosphate, nitrate, and ammonia is shown by boxplot in Figure 6.

Table 2. Percentage of relative absorption value of TOM: organic matter, PO_4^{3-}: phosphate, NO_3^-: nitrate, and NH_3: ammonia, for each species of aquatic plants.

Aquatic plant species	Relative Absorption (%)			
	PO_4^{3-}	NO_3^-	NH_3	TOM
Water Hyacinth (*Eichornia crassipes*), EG	-57	100	-2525	85
Pickerelweed (*Monochoria vaginalis*), EL	-950	100	-4817	93
Water Spinach (*Ipomoea aquatica*), KG	-807	100	-6442	75
Water Primrose (*Ludwigia ascedences*), TD	-121	100	-3775	87
Water Lettuce (*Pistia stratiotes*), KA	-618	100	-1608	95
Giant Salvinia (*Salvinia molesta*), KM	-807	100	-2358	84
Hornwort(*Ceratophyllum demersum*), CER	-929	88	-1692	80

Note : The positive (+) indicates a reduction in concentration from the initial, while the negative (-) means an increase in concentration from the initial (surplus or additional concentration).

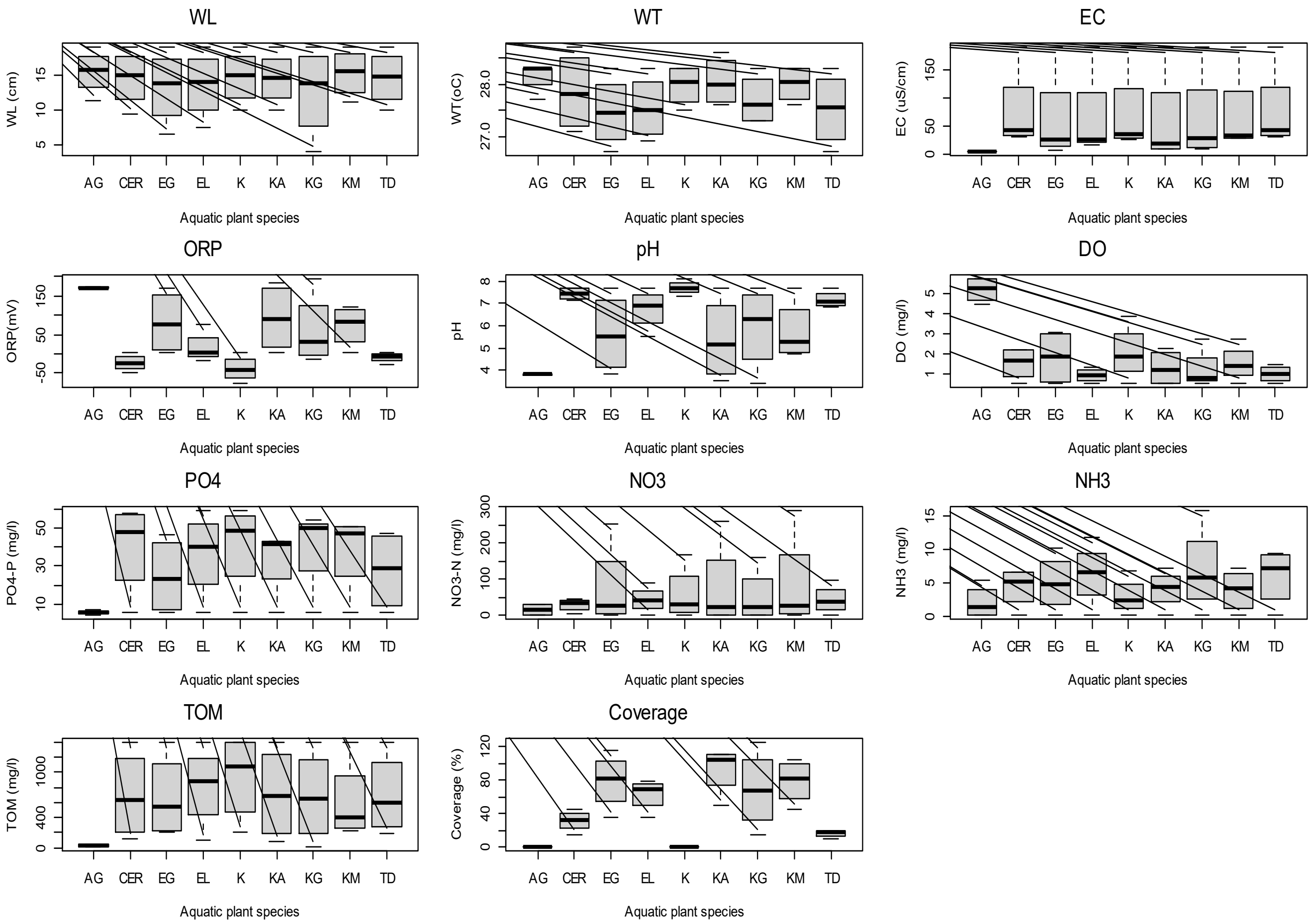

Figure 6. Boxplot shows the WL: water surface, WT: water temperature, EC: electrical conductivity, ORP: oxidation-reduction potential, pH, and DO: dissolved oxygen, PO_4: phosphate, NO_3: nitrate, NH_3: ammonia and TOM: organic matter, during the experiment for 4 times of sampling at each experimental unit, EG: water hyacinth, EL: pickerel weed, KA: water spinach, TD: water primrose, KA: water lettuce, KA: giant Salvinia, CER: hornwort and control (K) and pure peat water (AG).

The relationship between each PO_4, NO_3, and NH_3 to the percentage of coverage (Cov) indirectly was an indication of aquatic plant growth revealed by the biplot graph of PCA (Figure 7). A positive correlation occurred between PO_4 and Cov as well as NH_3 and Cov, but a negative correlation was found between NO_3 and Cov. It was explained by 51% of the variance of data (as PC1 axis) of the PCA, even though it is not significant by Spearman's correlation (Table 3). This means that the absorption of nutrients in the form of phosphorus and nitrogen from wastewater by aquatic plants occurs. A negative correlation was detected between TOM and PO_4, as well as TOM and NH_3. In turn, there was a positive correlation between TOM and NO_3 according to PCA (PC1 axis of biplot). Such PCA result is supported by the Spearman correlation coefficient, in which there was a significant correlation between TOM both with PO_4 (rho = -0.52, p = 0.0025) and NH_3 (rho = -0.61, p = 0.0002) and with NO_3 (rho = 0.51, p = 0.0027). This means that during incubation organic matter was possibly decomposed into inorganic nutrients, such as phosphorus and nitrogen.

All correlation coefficients among parameters are presented in Table 4.

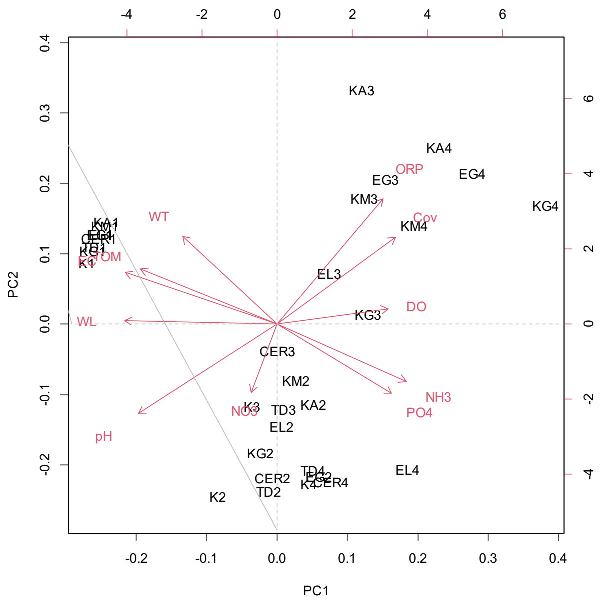

Figure 7. Biplot principal component analysis (PCA) visualizing the relationship between parameters WL: water surface, WT: water temperature, EC: electrical conductivity, ORP: oxidation-reduction potential, pH, DO: dissolved oxygen, Cov: closure, TOM: total organic matter, PO4: phosphate, NO3: nitrate and NH4: ammonia. The objects (n = 33) are each species of aquatic plant, cf. Table 3, for 4 observations (sampling). Axis 1 (PC1) contributed 51% of the variance and axis 2 (PC2) 18%, accounting for 69% of the total variance.

The wastewater of African catfish culture absorbed by aquatic plants in this study was direct without pre-treatment. Chemical processes such as reduction-oxidation and aerobic bacterial activity become very important in converting organic matter into inorganic compounds, i.e. phosphorus and nitrogen with the availability of oxygen. The presence of oxygen occurs naturally from aquatic plant species through their root systems. In this case, DO and ORP were positively correlated, indicating that the redox process occurred that is supported by available oxygen in the water. Further, DO has a significantly positive correlation with PO_4, suggesting that the decomposition of organic matter might occurred aerobically into phosphate. On the other hand, DO had a significant negative correlation with NO_3, possibly a nitrification process that reduced oxygen. This denoted that at the same time, NO_3 and NH_3 had a significant negative correlation, although perhaps some of these processes did not optimally happen (Table 3).

The existence of pH as the controlling factor to the chemical reactions and metabolism of the organism in waters, showed a significant correlation between pH and main parameters i.e. PO_4, NO_3, NH_3, and TOM as shown by Spearman rank correlation in Table 3. An increasing pH in the experimental unit during incubation tended to decrease the concentration of PO_4, and NH_3 but was in reverse towards NO_3 and TOM. On the other hand, the coverage level of aquatic plants was inversely proportional to the pH (rho = -0.81, p = 0.0000).

Total organic matter (TOM) was significantly correlated with all physicochemical parameters measured except ORP as shown in Table 3. TOM was significantly negative correlated with PO_4 (rho = -0.52, p = 0.0025) and NH_3 (rho = -0.61, p = 0.0002), and positively correlated with NO_3 (rho = 0.51, p = 0.0027). This is also clearly shown by the biplot PCA in Figure 7. A negative correlation between TOM and both PO_4 and NH_3 indicated that the organic waste of African catfish decomposed to form inorganic nutrients such as phosphate and ammonia. However, NO_3 increased as increasing of TOM. It means that nitrification occurred rapidly as the conversion of nitrite to nitrate was supported possibly by oxygen which was indicated by a significant negative correlation between NO_3 and DO (rho = -0.58, p = 0.0004).

Table 3. Spearman rank correlation (rho) and p-value (p) between the physical-chemical parameters of water and aquatic plant cover (n = 33, data cf. Table 1).

	WL	WT	EC	pH	ORP	DO	PO_4	NO_3	NH_3	TOM	Cov

WL		0.52**	0.85***	0.67***	-0.28	-0.76***	-0.66***	0.76***	-0.58***	0.77***	-0.4*
WT	0.0025		0.32	0.36*	0.03	-0.27	-0.25	0.1	-0.63***	0.64***	-0.15
EC	0.0000	0.0742		0.81***	-0.49**	-0.73***	-0.56***	0.61***	-0.51***	0.66***	-0.63***
pH	0.0000	0.0440	0.0000		-0.73***	-0.57***	-0.4*	0.41*	-0.58***	0.55**	-0.81***
ORP	0.1239	0.8526	0.0044	0.0000		0.14	-0.09	-0.31	0.1	-0.15	0.85***
DO	0.0000	0.1333	0.0000	0.0006	0.4337		0.66***	-0.58***	0.36*	-0.51**	0.28
PO4	0.0000	0.1636	0.0008	0.0216	0.6181	0.0000		-0.36*	0.49**	-0.52**	0.13
NO3	0.0000	0.5980	0.0002	0.0203	0.0893	0.0004	0.0459		-0.16	0.51**	-0.28
NH3	0.0005	0.0001	0.0031	0.0005	0.5946	0.0438	0.0049	0.3823		-0.61**	0.37*
TOM	0.0000	0.0000	0.0000	0.0010	0.4243	0.0026	0.0025	0.0027	0.0002		-0.34
Cov	0.0236	0.4044	0.0001	0.0000	0.0000	0.1165	0.4734	0.1239	0.0392	0.0588	

Note : The value in the table is correlation coefficient, p-value, and asterisk symbol. * (*,**,&** are sig. respectively at ≤ 0.05, 0.01, & 0.001)

Discussion

1. Water quality parameters

Electrical conductivity (EC) in all of the aquatic plant basins showed a declining pattern, especially from sampling 1 to sampling 2, and the plate to sampling 4. The existence of aquatic plant species tended to decrease EC value. Oxidation-reduction potential (ORP) showed different trends to EC. In particular, for water hyacinth (EG), water spinach (KG), water lettuce (KA), and giant Salvinia (KM), the ORP values increased from sampling 1 to sampling 4. According to Xu *et al.* (2020), aquatic plants can reduce EC value and increase or improve ORP as well as dissolved oxygen (DO) in the swine manure wastewater treatment. In line with Xu *et al.* (2020); Wulandari *et al.* (2023), DO concentration during incubation mostly increased from sampling 1 to 4. It suggested that existing of aquatic plants can improve oxygen concentration in water.

Phosphate (PO_4) tended to increase during incubation as well as ammonia (NH_3). This pattern was slightly the same as the total phosphorus (TP), total nitrogen (TN), and ammonium (NH_4) increment pattern in the swine manure wastewater treatment using aquatic macrophytes (Xu *et al.*, 2020). However, as to Wulandari *et al.* (2023), the NH_3 pattern decreased by the time incubation. It might be due to the rapid conversion of ammonia to nitrate. Most of the aquatic plant treatment units decreased the nitrate concentration from sampling 2 to sampling 4. This variation was different somewhat from Xu *et al.* (2020). Further, total organic matter (TOM) decreased by fluctuation through incubation time, similar to giant Salvinia and water lettuce in Wulandari *et al.* (2023).

Concentrations of inorganic nutrients, during incubation, varied respectively with a median of phosphate, 43.2 mg/l, nitrate, 37.6 mg/l, and ammonia, 4.9 mg/l, and maximum values all above 15 mg/l, typical of municipal waste particularly for ammonia and phosphate in Indonesia (Widyarani *et al.*, 2022).

2. Coverage and absorption of aquatic plants

As aerial viewed coverage in Figure 4, water hyacinth (EG), water spinach (KG), water lettuce (KA), and giant Salvinia (KM) seemed to increase their growth if only were not limited by the basin space. Pickerelweed (EL), in turn, revealed slow growth in comparison to the previous four species which are free-floating macrophytes. Pickerelweed has the same family as water hyacinth, but it seems not truly a free-floating macrophyte. In the natural habitat, pickerelweed root mostly attaches to the muddy bottom of the waters. According to Moody (1989), pickerelweed exists in almost all rice fields which are waterlogged systems. This species is a semi-aquatic weed in the family Pontederiaceae, living in paddy fields throughout the rice-growing areas of the world. It is highly competitive and companionable because it has intermittent germination, fast growth, and high plasticity (Athira *et al.*, 2019). In the present treatment, pickerelweed absorbed nutrients directly from water and did not to the bottom sediment or water muddy. So, this species might not be growing well. According to Hariyadi (2020) pickerelweed is well used as a phytoremediator for chlorine waste, but in this treatment was still lower than other species, especially water lettuce, giant Salvinia, and water hyacinth (Table 2 and Figure 6). Pickerelweed presumably is a better growing and absorbs organic substance in the water muddy than in only water media. Setiawan *et al.* (2021) reported that pickerelweed can grow well in the appropriate combination of water and soil such as waterlogged.

Water primrose (TD), in many water bodies in Palangka Raya, is a free-floating macrophyte and often grows well on city ditches. However, its coverage was the lowest (median, 16%). This species seemed difficult to grow on dense wastewater in the present work. Although, Xu *et al.* (2020) reported that water primrose (L. *ascedences*) was growing well on swine manure wastewater.

The organic matter decomposition at all species of aquatic plants, as pointed out by TOM was above 70%, in which the highest absorption was in KA about 95%. The lowest TOM absorption of 75% was found in KG. The higher rate of total organic matter, TOM absorption in KA might be because the decaying organic matter in KA was better than others as denoted by the reduction-oxidation activity. The ORP value of KA (mean = 92.8 mV) was the highest. According to Astuti and Indriatmoko (2018), water lettuce was better at reducing organic matter reaching about 56% than water hyacinth (24%). Wulandari *et al.* (2023) reported that water lettuce (33%) more reduced organic matter than giant Salvinia (20%) for African catfish waste.

For NO_3, the uptake of almost all aquatic plant species was 100%, except for only the CER was 88%. The PO_4 and NH_3 were possibly also absorbed by aquatic plants during the incubation time. Unfortunately, they could not be detected clearly from the existing values, because their concentration tended to increase during the incubation period, in the other sense there a surplus occurred.

The surplus of PO_4 and NH_3 might be because of the existence of aquatic plants. The placement of aquatic plants triggered a large conversion of organic matter into phosphate and ammonia. For instance, let water hyacinth (EG), the initial concentration of PO_4 was 5.8 mg/l, then at the second, third, and fourth sampling, it increased respectively to 37.8, 46.2, and 8.8 mg/l. Similarly, for water lettuce (KA), from the initial 5.8 mg/l increased to 42.6, 40.8, and 40.2 mg/l, as shown in Table 1, as well as for other species. The same case occurred with NH_3, there was an increase several times from the initial concentration of 0.24 mg/l as in Table 1. According to Xu *et al.* (2020), the existence of aquatic plants can adjust pH, improve dissolved oxygen and ORP, and reduce electrical conductivity. The other reason was presumably the number of aquatic plants was not large enough to compensate for the density of wastewater. The amount of PO_4 might also be beyond the needs of aquatic plants to grow. On the other hand, the conversion of NH_3 to NO_3 through the nitrification process might be slightly slow or inadequate. As a result, it was the buildup of phosphate and ammonia.

Based on total organic matter differences among species were detected. Visually by the boxplot in Figure 6, giant Salvinia (KM) had the lowest TOM concentration among species, followed by water hyacinth (EG). This indicated that giant Salvinia was among the species largest reduced organic matter among plant species, followed by water hyacinth. This was in line with Novita *et al.* (2019) reported that these two species are among the highest in absorbing organic waste of tofu, as well as Ahmad & Adiningsih (2019) reported that water hyacinth is higher than water spinach in remediating tofu wastewater. *Eichhornia crassipes* and *Salvinia molesta* are known as among the most competitive and widespread water weeds in Lake Vembanad, India (Retnamma *et al.*, 2022).

The relationship between PO_4, NO_3, and NH_3 and coverage (Cov) indirectly as a manifestation of the growth of each aquatic plant species was visible visually from the trend of the PCA biplot graph in Figure 4. A positive correlation occurred between PO_4 and NH_3 as nutrient components with Cov, but the negative correlation was between Cov and NO_3 explained by 51% of the variance (PC1) in the PCA biplot, although there were no significant from Spearman's correlation (Table 4). This means that there was the absorption of nutrients in the form of phosphorus and nitrogen from these inorganic compounds. According to Beheary *et al.* (2019); Su *et al.* (2019); Sudiarto *et al.* (2019) aquatic plant species potentially take up phosphorus and nitrogen during plant growth from wastewater. According to Wulandari *et al.* (2023), both water lettuce and giant salvinia reduced ammonia by more than 97%.

The wastewater of African catfish culture absorbed by aquatic plants in this study was direct without pre-treatment. Chemical processes manifested by the reduction-oxidation process and aerobic bacterial activity in particular root systems become very important in converting organic matter into inorganic compounds, i.e. phosphorus and nitrogen elements with the availability of oxygen. The presence of oxygen occurs naturally from aquatic plant species through their roots. According to Gopal and Ghosh (2008), most free-floating plants transport oxygen to the water column through their roots. This statement is supported by Wang *et al.* (2018) that oxygen supplies radial oxygen loss (ROL) and carbon sources from root exudates in the root zone of the macrophyte.

Dissolved oxygen and ORP were positively correlated, an indication that the redox process occurred which was supported by oxygen. This situation is in line with Viet *et al.* (2008) which has found a positive relationship between dissolved oxygen, DO concentration, and ORP, ORP (mV) = 160.38 + 68 log [DO, mg/l].

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Conclusion

Of the seven species of aquatic plants tested for their phytoremediation abilities on African catfish wastewater, giant Salvinia is among the highest reducing total organic matter by about 95%. The highest coverage was water lettuce by 92%, followed by giant Salvinia (79%) and water hyacinth (78%). However, phosphate and ammonia have a negative value of the relative absorption for all aquatic plant species, meaning a surplus or increase in concentration during incubation. Absorption for phosphate and ammonia is detected from the median value of their lowest concentration. Water hyacinth and giant Salvinia are the highest for respectively absorbing phosphate and ammonia. All aquatic plant species have relative absorption on nitrate of 100%, except hornwort of 88%; the best absorption of nitrate is water lettuce. In conclusion, giant Salvinia is the best at absorbing organic waste, followed by water hyacinth. Whereas, the best growing by coverage is water lettuce.

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