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# Evaluating the Effectiveness of Wetland Plants in Removing Pollutants from Condensate Water at PT Supreme Energy Muara Laboh, West Sumatra, Indonesia

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**ABSTRACT**

PT Supreme Energy is a company engaged in developing geothermal energy to produce electricity. In the operation of Geothermal Power Plants (GPP), water vapor is extracted from the bowels of the earth, then the steam is condensed into water. When the condensate produced by GPP is not reinjected, the water has the potential to produce pollutants. One method of processing pollutants is the phytoremediation technique, which uses aquatic plants with the construction of constructed wetlands. This research aims to test the effectiveness, adaptability, and removal ability of aquatic plants to reduce condensate water pollutants. This research used a Randomized Block Design (RBD) with 1 (level) of treatment. The treatment consisted of 10 types of aquatic plant seedlings. The research results showed that 9 types of plants had a survival rate above 100%, namely *H. coronarium* J. Koenig), *T. angustifolia, I. formosana, T. dealbata, A. calamus, J. effusus, P. umbrela, C. papyrus, D. bicolor*, while *N. alba* had a survival rate of 76%. Removal values for the parameters Fe, Cu, Co, Bo, pH, BOD, COD, Ammonia, Nitrite, Nitrate and TSS show varying results for each cell/plant. Specifically for Co metal, the removal value is 0 in each cell. The highest removal was found in Cell 2 (treatment of *H. coronarium* and *T. angustifolia* plants) with Fe metal removal values (41.07%), pH (3.97%), ammonia (16.25%), nitrate (33.11%) and TSS values (33.78%). Removal of metals, Cu (16.67%) and Bo (19.11%), COD (56.65%), and nitrite (0.05%) were found in Cell 5 (treatment of *P. umbrella* and *C. papyrus* plants). So, *H. coronarium, T. angustifolia, P. umbrella* and *C. papyrus* can be used as phytoremediation plants to reduce pollutants, especially pollutants in condensate.

## 1. INTRODUCTION

PT Supreme Energy Muara Laboh is a large international company engaged in the development of geothermal energy to produce electricity. In South Solok Regency there is geothermal potential which has been explored by PT Supreme Energy Muara Laboh. This company was founded in 2008 as a Geothermal Permit holder for the Liki-Pinang Awan Muara Laboh Geothermal Working Area (GWA), South Solok Regency, West Sumatra Province. Geothermal energy is one of the renewable energies in Indonesia that has been used for Geothermal Power Plants (GPP). Countries that have a large revival capacity from GPP are as follows (e.g. 1. The United States, with a GPP capacity of 3093 MW. 2. Philippines with a GPP capacity of 1904 MW. 3. Indonesia with GPP capacity is 1197 MW) [1]. As of December 2015. Indonesia has harnessed its geothermal resources for electricity generation in 10 locations nationwide, boasting a total installed capacity of 1438.5 MW from a geothermal power plant [2], based on Law Number 21 of 2014 concerning Heat Earth. Geothermal is a source of heat energy contained in hot water, water vapor, and rocks along with associated minerals and other gases that cannot be genetically separated in a geothermal system. Define geothermal heat as the heat contained in the earth which occurs as a result of geological phenomena [3].

In general, geothermal utilization consists of two types, namely direct utilization and indirect utilization. Geothermal heat has been utilized to date, both for direct use and indirect use, namely for electricity generation [4]. Direct use of geothermal heat can be used for various activities, including agriculture, fisheries, and tourism. Direct use of geothermal heat from 20 ºC to more than 100 ºC. In accordance with current technological developments, direct use of geothermal heat can also be used to generate electricity. Hot water that comes from geothermal manifestations can be used to generate electricity.

GPP consist of 4 types of generators [5]. The first type of generator is Single-Flash Steam Power Plants and the second is Double-Flash Steam Power Plants. The third type of generator is Dry-Steam Power Plants and the fourth is Binary Cycle Power Plants. GPP operations do not require primary energy to drive turbines, this is because water vapor is extracted from the bowels of the earth through production wells. The steam produced by the well is separated by a separator, resulting in steam and brine. Brine is the liquid phase resulting from the separation of geothermal steam in a separator. Steam is used to rotate the turbine. After turning the turbine, the steam condenses into water. This condensation water should be injected back into the reservoir to maintain the sustainability of the reservoir so that geothermal resources can continue to be sustainable. When the condensate produced by GPP is not reinjected, the water becomes waste/pollutant.

Under normal operating conditions, the Condensate Injection Pump (CIP) installed in the power plant will inject condensate water into the injection well, and then the condensate water will be discharged into surface river water bodies. However, as an alternative, injection will be carried out if there is an emergency condition in the condensate water treatment system. The government has regulated the quality standards for waste/pollutants produced by GPP. The regulation of waste quality standards is through Minister of Environment Regulation Number 19 of 2010 concerning Waste Water Quality Standards for Oil and Gas and Geothermal Businesses and/or Activities as well as Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. 5 of 2021 concerning Procedures for Issuing and Technical Approval and Operational Feasibility Letters in the Field of Environmental Pollution Control [6, 7]. Specifically for quality standards for wastewater disposal from Supreme Energy Muara Laboh GPP condensate, waste quality standards have been determined in accordance with the Technical Approval for Fulfillment of Quality Standards for Waste Water Disposal to Surface Water Bodies of PT Supreme Energy Muara Laboh No. S.146/PPKL/PPA/PKL-2/2/2023 which was issued on February 23, 2023.

Based on the impacts caused, it is necessary to increase awareness of the importance of owning a waste Water Treatment Plant (WTP) in processing polluted waste before it is discharged into the environment or river bodies. Several studies have grouped waste/pollutant processing methods into 4, namely biodegradation, electrocoagulation, membranes and biofilters [8]. One way that can be done to reduce water pollution is with a biodegradable activated sludge system [9]. However, this method requires quite a long time and is relatively expensive so it is less effective in managing wastewater. Another method that can be used to process waste is by using a trickling filter. However, this method requires several process stages, chemicals, and produces residues that are dangerous to health [10]. Based on several methods of processing waste contamination, it is necessary to test the effectiveness of another method, namely the phytoremediation technique using one component, namely planting aquatic plants with the construction of a constructed wetland.

Constructed wetland or known as artificial wetland is an application of eco-drainage, with the aim of improving water quality, water quantity, water conservation, ecological restoration and also creating beauty, aesthetics and friendliness [11]. Constructed wetland is a controlled wastewater treatment system built using natural processes. Wastewater treatment using the constructed wetland method has been widely applied in developed countries such as China [12], Turkey [13] and Germany [14]. Constructed wetland arrangements include sandy soil, plants and the help of other organisms to process wastewater or wastewater [15]. The advantage of constructed wetlands compared to conventional wastewater treatment facilities is lower investment, operation and maintenance costs. Constructed wetlands are built to treat wastewater, reduce the harmful effects of waste, and in an effort to improve water quality [16]. So far, research on the use of wetland plants to absorb pollutants has only been carried out on household waste, hospitals and a small part in certain industries, specifically for condensate waste from Geothermal Power Plants (GPP) that has not been carried out, so this is the latest in this research. This research aims to investigate the efficacy, adaptability, and removal efficiency of 10 aquatic plant species in mitigating pollutants from the condensate water at PT Supreme Energy Muara Laboh.

## 2. MATERIAL AND METHOD

### 2.1 Time and place of research

This research was conducted in the working area of PT. Supreme Energy Muara Laboh, South Solok, West Sumatra Indonesia. The research period was carried out for 6 months, starting from January 2024 to June 2024. The wetland installation was made at the end of January 2024, and initial data collection was carried out from the beginning of February 2024 to June 2024.

### 2.2 Materials and tools

The materials used in this research were aquatic plant seeds consisting of 10 types, namely gandasuli (*Hedychium coronarium* J. Koenig), *Typha angustifolia*, *Iris formosana*, *Thalia dealbata*, *Acorus calamus*, *Juncus effuses*, *Cyperus umbrela*, *Cyperus papyrus*, *Dietes bicolor*, and *Nymphaea alba*, soil, sand, palm fiber, gravel and water. Tools used are calipers, digital scales, oven, ruler with an accuracy of 1 cm, pH meter, thermometer, 20-liter plastic bucket, and miniature wetland Installation measuring 200 cm × 100 cm × 100 cm with 6 cells.

### 2.3 Research design

The research used a Randomized Block Design (RBD) with 1 (level) of treatment. In this study, the focus of the treatment is on the difference in types of wetland plants used, so that this difference becomes the group in the research design. Another consideration for using RBD is to reduce bias in the study by ensuring that participants are randomly assigned to groups, increasing the objectivity of the study by ensuring that the results are not influenced by unrelated factors, and controlling for extraneous variables that may affect the study results. The groups used in this research were Cell-1/Control, Cell-2 (*H. coronarium* J. Koenig and *T. angustifolia* plants, Cell-3 (*I. formosana* and *T. dealbata* plants), Cell-4 (*A. calamus* and *J. effuses* plants, Cell -5 (*C.umbrella* and *C. papyrus* plants) and Cell-6 (*D. bicolor* and *N. alba* plants. Each treatment level consisted of 25 seedlings with 2 types of aquatic plants so that each cell contained 50 plants. So, the total number of aquatic plant seedlings used in this research consisted of 250 seedlings.

The linear model of the RBD used in this research is as follows [17].

$$\mathrm{Yij} = \mu + \tau i + \beta j + \varepsilon \mathrm{ij}$$

Information:
i =1,2, j=1,2, r=1,2
Yij: Observation results in the ith treatment and jth group
r: replicated

μ: Population mean
τi: Additive effect of group i
βj: Additive effect of the jth group
εij: Random effect of the ith treatment on the jth group

### 2.4 Wetland installation design

Design and construction of wetland installations in the field for PT wetland IPAL studies. Supreme Energy can be seen in Figure 1.


**Figure 1.** Design and construction of installation and materials used for wetland study

### 2.5 Research implementation

2.5.1 Selection of aquatic plant types

Plants that can be used in wetland systems are plants that can withstand high levels of nutrient loads and organic material and are resistant to stressful conditions such as waterlogging and low oxygen content, and have dense root systems for microorganisms to attach to. Aquatic plants can effectively augment wastewater treatment by mitigating organic matter and nutrient level, particularly nitrogen and phosphorus [18].

Furthermore, the selected wetland plants must have high pollutant absorption capacity, tolerance to extreme environmental conditions such as pH and temperature changes, adaptability to changing environmental conditions, ability to regenerate after damage, and importantly, consideration of non-invasive plant species and availability of seeds in the surrounding area. Based on the criteria above, for Constructed Wetland at PT. SEML are plants that can be used in wetland systems, namely *H. coronarium* J. Koenig, *T. angustifolia*, *I. formosana*, *T. dealbata, A. calamus, J. effusus, P. umbrela, C. papyrus, D. bicolor*, and *N. alba.* Types and characteristics of aquatic plants planted in each wetland cell (Table 1). Planting pattern can be seen in Figure 2.

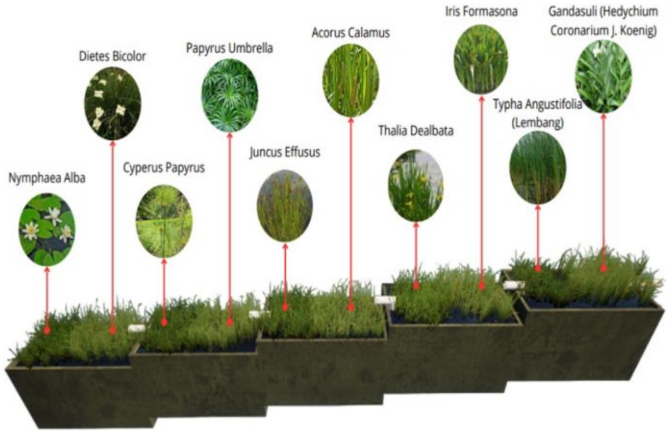


**Figure 2.** Pattern and layout of wetland planting

2.5.2 Preparation of aquatic plant seedlings

The seeds of ten species of aquatic plants used in this research were obtained or purchased from aquatic plant nurseries located around Bogor, West Java. The aquatic plant seeds in this study used seeds with good uniformity. The indicators of uniformity are the age and height of the seedlings. Then the aquatic plant seeds are cleaned of adhering dirt and then acclimatized. Preconditioning of aquatic plant seeds and acclimatization was carried out for seven days before the research was carried out (Figure 3). The aim of acclimatization is so that the seeds are able to adapt to new environmental conditions, eliminating other substances or compounds present in the plant.

**Figure 3.** Preconditioning of aquatic plant seeds in the nursery before planting in the wetland installation

**Table 1.** Types of aquatic plants planted in each wetland cell

| Scientific Name | Local Name | Family | Information |
|---|---|---|---|
| Control | - | - | - |
| *T. angustifolia* | Lembang | Typhaceae | Not invasive |
| *H. coronarium* | Gandasuli | Zingiberaceae | Not invasive |
| *T. dealbata* | Kana air | Marantaceae | Not invasive |
| *I. formosana* | Iris bunga ungu | Iridaceae | Not invasive |
| *J. effucus* | Rumput lunak | Juncaceae | Not invasive |
| *A. calamus* | Jerangau | Araceae | Not invasive |
| *C. papyrus* | Rumput teki rawa | Cyperaceae | Not invasive |
| *C. umbrella* | Rumput teki payung | Cyperaceae | Not invasive |
| *N. alba* | Teratai | Nymphaeaceae | Not invasive |
| *D. bicolor* | Iris kuning liar | Iridaceae | Not invasive |

2.5.3 Wetland installations in the field

Before starting activities, the research team previously held a jobs safety meeting, and then the research team determined the location point and leveling area before installing the wetland installation at PT. Supreme Energy, and then set up the wetland installation and fill in the material (Figure 4).

**Figure 4.** Wetland installation settings and materials filling

2.5.4 Planting plants and diverting waste water to cell wetland

The planting technique is carried out by planting seeds whose size for each type is relatively uniform. The spacing between plants is 20 cm × 20 cm. In each cell, 2 types of aquatic plants are planted with 25 seedlings for each type, so that each cell has 50 plants. So, the total number of aquatic plant seedlings used in this research was 250 seedlings. Furthermore, after the wetland plants have been planted, the wastewater/pollutants are finally flowed into each cell (Figure 5).

**Figure 5.** Irrigation of wastewater to the wetland cell

**2.6 Research observation parameters**

2.6.1 Plant height increase (cm)

The height of aquatic plant seeds is measured using a ruler from the base to the tip/shoot of the aquatic plant. Height measurements were taken once a week during the study.

2.6.2 Increase in seedling diameter (mm)

Stem diameter measurements were carried out using calipers at a distance of 1 cm from the base of the bottom of the aquatic plant. This measurement was carried out once a week during the study.

2.6.3 Number of saplings

The aquatic plant saplings that are counted are the saplings that emerge from each clump that appears or grows on the rhizoma of the stem. This data was calculated manually by counting each seedling that grew during the research. The number of offspring was counted once a week, starting from the beginning of the observation until the end of the 20-week observation.

2.6.4 Adaptability of aquatic plants

The adaptability and effectiveness of aquatic plants are carried out by comparing the percent survival value of each type of aquatic plant growing in each wetland cell. The highest percent survival value of aquatic plant seeds indicates their high adaptability to wastewater. Calculation of the percent survival of aquatic plants was carried out at the end of the research using the formula [19].

$$Live\ percentage(\%) = \frac{\text{Number of viable seedling } \times 100}{\text{Number of seedling planted}}$$

2.6.5 Soil media analysis

Soil samples collection for laboratory testing. Soil sampling at the site or around the PT SEM location, South Solok, West Sumatra Province. To obtain data regarding the physical and chemical properties of the soil, soil samples were taken and then analyzed at the PT ICBB Laboratory. Biodiversity Biotechnology Indonesia.

2.6.6 Water quality analysis

Water quality analysis was carried out at the beginning and end of the research at the PT Sucofindo Laboratory, to see the pollutant content contained in the water before and after remediation, the water quality analyzed are water quality standard parameters such as; TSS analysis and chemical analysis/content of Fe, Bo, Co, Cu, Ammonia, Nitrite, Nitrate, pH, Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).

**2.7 Data analysis**

The analysis carried out to process research data is as follows.

2.7.1 Homogeneity test

The homogeneity of variance test is used to determine whether a set of research data has the same variance. The homogeneity of variance test was carried out using the Chi-Square test statistic. Calculation of test statistics is carried out using the following formula [20].

$$X^2\text{count} = (ln\,1\,0)\left\{B - \sum_i (ni-1)\,log\,S\,i^2\right\}$$

$$B = (log\,s^2)\sum i\,(ni-1)$$

$$S^2 = \frac{\sum\{(\mathrm{ni}^2-1)\mathrm{Si}^2\}}{\sum(ni-1)}$$

Information:
n = Number of data
B = Bartlett unit price
$Si^2$ = Data variance for each 1st group
ln 10 = 2,3026

The calculated X2 value compared to the X2 table value. Populations have homogeneous variance if calculated X2 < X2 table. Populations have non-homogeneous variances if H0 is rejected or X2 calculated > X2 table.

2.7.2 Water quality analysis

Analysis of variance in this study used the F test at an accuracy level of 5%. Variance detection is carried out to test the hypothesis of whether treatment or fixed factors or fixed variables influence the response variable [21]. This analysis uses SPPS Software Version 10.01. Furthermore, if the F test results show F-count > F-table then there is a real effect of the treatment given and will be continued with a test of the difference in treatment mean values. However, if the results show F-count < F-table then there is no real effect from the treatment given so there is no need to test the difference in treatment mean values. The mean difference test model used in this research is the Least Significant Difference (LSD) test.

## 3. RESULTS AND DISCUSSION

### 3.1 Analysis of wetland plant growing media

An indication of the poor fertility level of a soil medium used to grow plants can be seen from the soil acidity level and the CEC value of the soil medium. Soil reaction shows the acidity of the soil which is expressed by the soil pH value. The pH value of the soil is very important in determining whether or not nutrients can be easily absorbed by plants and indicates the possibility of the presence of toxic elements in the soil [22]. Plants in soil that has high soil homogeneity (low pH) cannot absorb the P element because it is bound by the elements Al, Fe and Mn, and conversely, alkaline soil (high pH) cannot absorb the P element because it is bound by the Ca element. The pH value of acidic soil can be increased by adding lime to the soil and adding soil organic matter, while the pH of alkaline soil can be lowered by adding sulfur [22].

The soil chemical properties parameters analyzed include soil pH, soil organic matter, available P, cation exchange rate, and base saturation. Results of analysis of soil chemical properties at the site around the location of PT. Supreme Energi Muara Laboh (Table 2).

Based on the results of laboratory analysis, it can be seen that the pH and CEC values of the soil media used for the wetland plant growing media are around 6.1 (Table 2) which is categorized as slightly acidic and the CEC value is 26.91 (Table 3) which is included in the high category, so the soil media used wetland plants are quite good for growing plants. The level of fertility of a soil medium can be seen from the large cation exchange capacity (CEC) value, soil that has a low CEC will not be able to absorb and provide nutrients for plant growth. If the CEC value of the soil is high, the exchange of ions in the soil can run well so that plants can grow well and optimally. The magnitude of the CEC value is influenced by several factors including the amount of klei content, organic matter, and soil pH [23].

Furthermore, the organic C content is classified as very high with a value of 5.74%, and N is classified as moderate with a value of 0.46% (Table 2) in the soil media used for growing media for wetland plants around the PT SEML location. Organic matter has an important role in soil quality, where a decrease in organic C indicates a decrease in soil quality and conversely, if the organic C content is high then this condition is very good for plant growth [24]. Where these conditions can increase the soil's holding capacity, provide nutrients and water for plants, as well as encourage and maintain root growth, creating a suitable habitat for biotics can be influenced by the availability of organic material in the soil.

The P levels that can be absorbed by plants are water-soluble soil P and nitric acid. Based on an assessment of soil chemical properties, the P content available in the growing media for wetland plants is classified as very low with a value of < 3.60 ppm (Table 2) [25]. The low P value in soil media is thought to be influenced by the pH value of the soil which is classified as slightly acidic where the P element is bound by Al or Fe. Low P elements can result in stunted plant growth because cell division is disrupted.

**Table 2.** Results of pH, organic matter, pavailable analysis

| **Research Location** | **pH** | | **Organic Material** | | | **P tersedia** | |
|---|---|---|---|---|---|---|---|
| | $H_2O$ | KCl | C | N | C/N | Bray | Olsen |
| | | | ........... % .......... | | | Ppm | |
| Wetland Planting Media | 6.1 | 5.4 | 5.24 | 0.46 | 11.39 | | < 3.60 |
| Category* | AM | M | ST | S | S | | SR |

Information: M = sour, AM = a bit sour, AA = somewhat alkaline, R = low, S = medium, SR = very low, ST = very high

**Table 3.** Results of cation exchange rates and base saturation analysis of wetland planting media

| **Research Location** | **Cation Exchange Capacity** | | | | | **KB** |
|---|---|---|---|---|---|---|
| | Ca | Fe | K | Al | KTK | |
| | ................ cmolc $kg^{-1}$........... | | | | | % |
| Wetland plant medium | 15.68 | 104388.34 | 1.85 | < 0.04 | 26.91 | - |
| Category*) | T | ST | S | SR | T | - |

Information: R = low, S = medium, SR = very low, ST = very high, KTK = cation exchange capacity, KB = base saturation

The Ca content in the growing medium for wetland plants is relatively high. The content of other nutrients such as Fe is classified as very high and K is classified as moderate, as well as the Al element content is very low and is present in very small amounts in the soil media, with a value of < 0.04 (Table 3). The crucial problem with the growing media for wetland plants is the very high Fe element content. Fe is a type of heavy metal that is dangerous and toxic to plants if the amount is too high in the soil. The Fe element can strongly bind other essential nutrients in the form of compounds, so that these essential nutrients cannot be properly absorbed by plants.

**Table 4.** Results of analysis of variance (Anova) parameters for increasing height of wetland plants

| **Source Variants** | **DF** | **SS** | **MS** | **F-Value** | **$F_{table}$** | |
|---|---|---|---|---|---|---|
| | | | | | α=5 % | α=1 % |
| Replication | 24 | 1103.9254 | 45.9969 | 0.785 ns | 1.568 | 1.879 |
| Species | 9 | 37104.3686 | 4122.7076 | 70.316 ** | 1.923 | 2.490 |
| Error | 216 | 12664.2434 | 58.6308 | | | |
| Total | 249 | 50872.5374 | | | | |

*Information*: * = Significantly different at the 5% level, ** = Significantly different at the 1% level; ns = The different not significant.

The condition of base saturation (BS) is linearly related to the Ca content and pH in the soil. In the wetland plant growing medium, the Ca content is quite high, so it can be concluded that the base saturation is also high. Other studies have stated that base saturation is linearly related to soil pH [26, 27]. This means that if the pH is low, the base saturation is low and conversely, if the pH is high, the base saturation will also be higher. This means that in this case it can be concluded that by looking at the results of laboratory analysis of the chemical properties of the soil used as a planting medium for wetland plants, the soil media is quite acceptable.

### 3.2 Wetland plant growth analysis

3.2.1 Height growth of wetland plants

Based on the results of the analysis of variance (Anova), the wetland plant types in all cells had a very significant influence on the parameters of plant height increase (Table 4). The highest average value of increase in plant height was found in the *C. papyrus* type when compared with 9 other types of Wetland plants, with an average value of increase in height of 36.13 cm. The difference in the significance value of the increase in height is also presented in Figure 6.

3.2.2 Height growth of wetland plants

Based on the results of the analysis of variance (Anova), the wetland plant types in all cells had a very significant influence on the parameters of increasing plant diameter (Table 5). The highest average value of increase in plant diameter was found in the *C. papyrus* type when compared with 9 other types of wetland plants, with an average value of increase in diameter of 6.73 cm. The difference in the significance value of the increase in height is also presented in Figure 7.

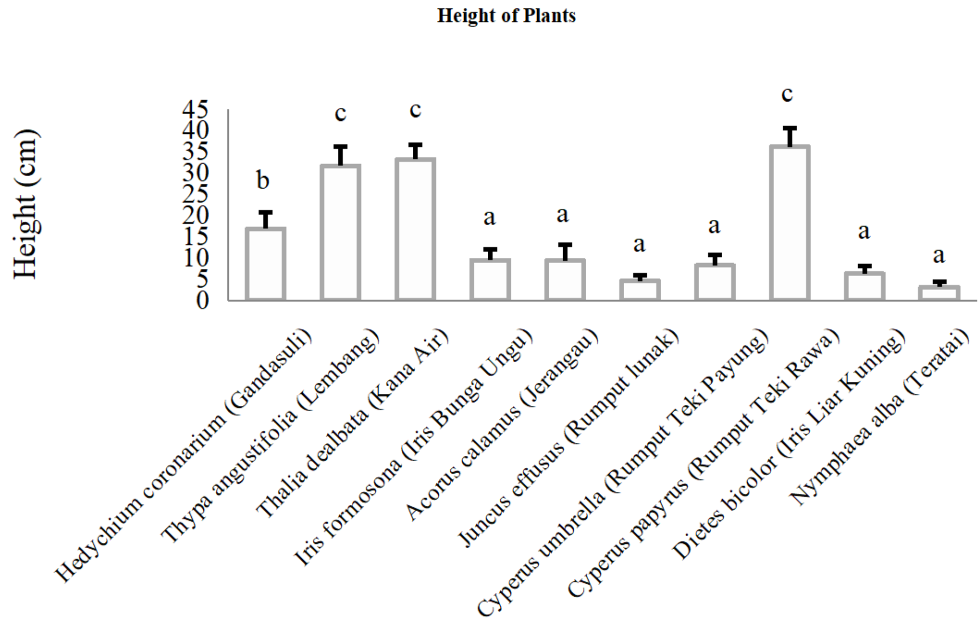


**Figure 6.** Average height increase of wetland plants

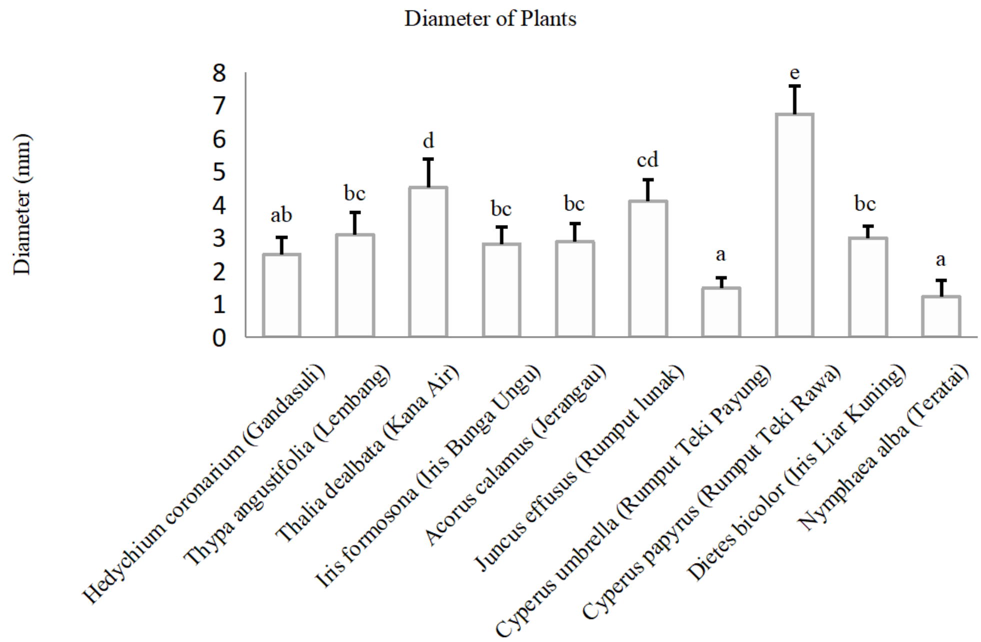


**Figure 7.** Average increase in diameter of wetland plants

**Table 5.** Results of analysis of variance parameters for increasing the diameter of wetland plants

| Source Variants | DF | SS | MS | F-Value | $F_{table}$ | |
|---|---|---|---|---|---|---|
| | | | | | α=5% | α=1% |
| Replication | 24 | 58.3036 | 2.4293 | 1.141 ns | 1.568 | 1.879 |
| Species | 9 | 566.0694 | 62.8966 | 29.554 ** | 1.923 | 2.490 |
| Error | 216 | 459.6936 | 2.1282 | | | |
| Total | 249 | 1084.0666 | | | | |

*Information*: * = Significantly different at the 5% level, ** = Significantly different at the 1% level; ns = The different not significant.

3.2.3 Number of wetland plant saplings

Based on the results of the analysis of variance (Anova), the wetland plant types in all cells had a very significant influence on the parameters for increasing the number of seedling (Table 6). The highest average value of increase in the number of plant saplings was found in the *J. effusus* (soft grass) type when compared with 9 other types of wetland plants, with the average value of increase in the number of plant saplings/saplings being 45.40. The difference in the significance value of the increase in height is also presented in Figure 8.

**Table 6.** Results of analysis of variance parameters for increase in wetland plant saplings

| Source Variants | DF | SS | MS | F-Value | $F_{table}$ | |
|---|---|---|---|---|---|---|
| | | | | | α=5% | α=1% |
| Replication | 24 | 219.9760 | 9.1657 | 1.146 ns | 1.568 | 1.879 |
| Species | 9 | 39803.1560 | 4422.5729 | 552.968 ** | 1.923 | 2.490 |
| Error | 216 | 1727.5440 | 7.9979 | | | |
| Total | 249 | 41750.6760 | | | | |

*Information*: *=Significantly different at the 5% level, **=Significantly different at the 1% level; ns=The different not significant.

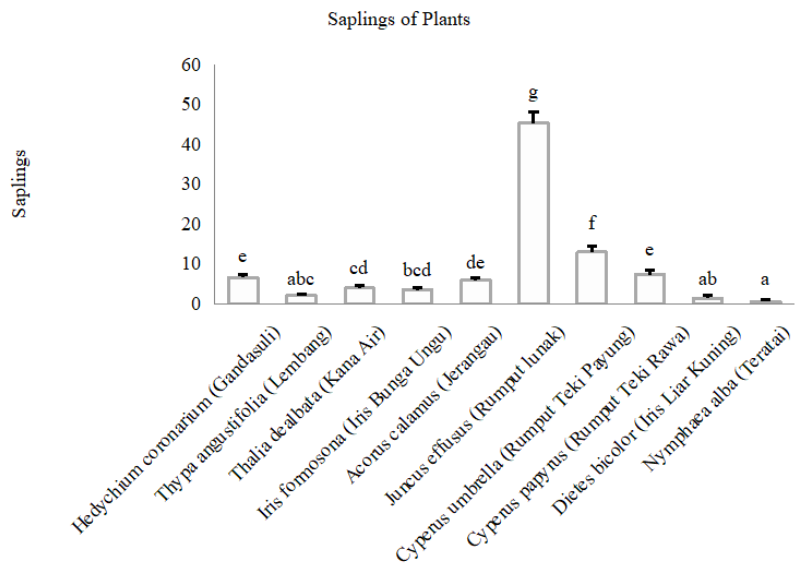


**Figure 8.** Average increase in wetland plant saplings

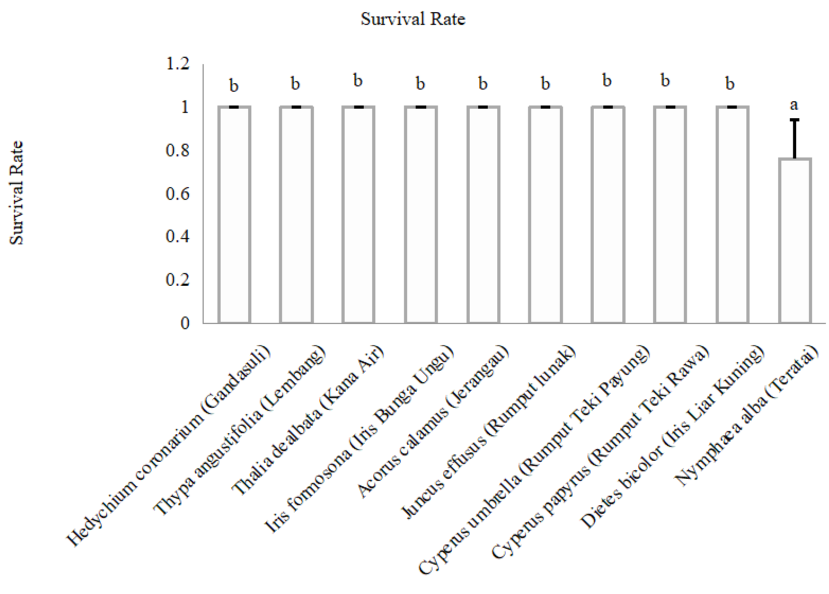


**Figure 9.** Average survival rate for all wetland plants

3.2.4 Wetland plant survival rate parameters

Based on the results of analysis of variance (Anova), wetland plant types in all cells had a very significant influence on survival rate parameters (Table 7). The average plant survival rate reached 100% and the highest value was found in 9 types of wetland plants, and only 1 type of wetland plant had a survival rate of 76%, namely the *N. alba*. The difference in the significance value of the increase in height is also presented in Figure 9.

**Table 7.** Results of variance analysis of wetland plant survival rate parameters

| Source Variants | DF | SS | MS | F-Value | $F_{table}$ | |
|---|---|---|---|---|---|---|
| | | | | | α=5% | α=1% |
| Replication | 24 | 0.4560 | 0.0190 | 1.000 ns | 1.568 | 1.879 |
| Species | 9 | 1.2960 | 0.1440 | 7.579 ** | 1.923 | 2.490 |
| Error | 216 | 4.1040 | 0.0190 | | | |
| Total | 249 | 5.8560 | | | | |

*Information*: * = Significantly different at the 5% level, ** = Significantly different at the 1% level; ns = The different not significant.

The percentage of plant life is an observation of the number of plants that are alive throughout the observation time. The viability or percentage of plant life is a condition for success in activities related to planting, one of the criteria for successful growth is that the plant is healthy and has optimal growth. This percentage of life is seen during the research process. Based on the results of observations and research carried out, of the 10 types of Wetland plants planted (Figure 10) only 1 type of plant whose growth percentage did not reach 100%, namely the *N. alba* type with a growth percentage of 76%. Some of the *N. alba* plants were rotten and dead (Figure 10).

(A) (B)

**Figure 10.** Condition of (A) N. alba plants; (B) N. alba plant rot on the tuber

Out of 10 wetland plants species cultivated, 9 types had a growth percentage of 100%, only 1 type of plant had a growth percentage of 76%, namely *N. alba*. Furthermore, of the 9 types, there is 1 type whose leaf growth is not good, namely the *A. calamus* type where the tips of the leaves turn yellow and the condition of the leaves tends to have spots (Figure 11), this indicates that the plant's growth is not optimal, this is thought to be due to the influence of the growing media which is less supportive. So, the plants cannot adapt well. Furthermore, plant growth can also be influenced by climate factors such as weather, humidity and temperature, this causes plants to be susceptible to disease if environmental conditions are not suitable and stable [28].

**Figure 11.** Growth conditions of *A. calamus* leaves

**3.3 Analysis of wastewater quality in wetland**

Wastewater is the remainder of a business and/or activity in liquid form, where the main process is the process that produces waste water originating from the washing process (with or without chemicals) of all metal equipment, cooling tower blowdown, boiler blowdown, laboratory, and regeneration of resin water treatment plants. Wastewater from a business must comply with waste water quality standards and be below the maximum level of wastewater, namely the highest level that is still permitted to be discharged into the environment. So that wastewater that is disposed of must comply with waste water quality standards, namely the limit size or level of pollutant elements and/or the number of pollutant elements that are allowed to exist in wastewater that will be disposed of or released into the water source of a business and/or activity.

This can be done with a Water Treatment Plant (WTP) or demineralization, which is the process of purifying raw water for processing and domestic purposes. Based on the results of the initial analysis and the results of the final analysis of the water quality at the inlet, almost all parameters analyzed meet the quality standards, (Reference Standards of Minister of Environment Regulation No. 8 of 2009, Minister of Environment Regulation No. 19 of 2010, as well as Technical Approval S.146/PPM/ PPA/PM.2/2/2023).

From the results of research on the initial analysis of wastewater quality (Table 8) for several parameters analyzed, it is known that the solids content in this wastewater can be reduced by a physical process, namely sedimentation. In this constructed wetland system, wastewater flows through soil particles with sufficient detention time. The media depth and certain speed will provide an opportunity for solid particles to settle and sedimentation events occur in wastewater [29]. Based on the Minister of Environment Regulation No. 08 of 2009 where the maximum permitted level of Total Suspended Solid (TSS) in wastewater is 100 mg/L, while the results of the analysis of wastewater TSS parameters in each wetland Cell analyzed are different and the value is still far from the maximum allowable wastewater TSS levels. The results of the wastewater TSS parameter analysis at the end of the observation showed that the TSS value for each wetland Cell was < 10 mg/L and this value was still far from the maximum allowable wastewater TSS level. And when compared with the results of the analysis at the beginning of the observation (Table 8), the TSS value experienced a fairly large decrease.

Furthermore, for the heavy metal parameters Co, Cu, heavy metal content values were obtained which were still much lower than the maximum permitted heavy metal content (meets quality standards/above standard). For the analysis of heavy metal content, if we compare the water quality analysis at the beginning of the observation with the water analysis at the end of the observation, for most of the heavy metals the values have not changed. However, there is an interesting thing for the heavy metal type Cu, where the value of Cu levels has decreased in removal reaching 16.67%, where the initial concentration value of 0.02 mg/L becomes < 0.004 mg/L, so that the reduction in the heavy metal Cu level reaches 0.016 mg/L. This happened to Cell-5 wetland.

**Table 8.** Results of wetland water quality analysis of PT. Supreme Energy Muara Laboh

| Parameter | Inlet | Cell 1 | Cell 2 | Cell 3 | Cell 4 | Cell 5 | Cell 6 |
|---|---|---|---|---|---|---|---|
| | | | | **Fe** | | | |
| Initial Analysis | 0,22 | 0,21 | 0,16 | 0,15 | 0,12 | 0,12 | 0,12 |
| Final Analysis | 0,12 | 0,24 | 0,10 | 0,10 | 0,06 | 0,07 | 0,08 |
| | | | | **Cu** | | | |
| Initial Analysis | 0,02 | 0,02 | 0,02 | 0,03 | 0,03 | 0,02 | 0,03 |
| Final Analysis | 0,004 | 0,004 | 0,004 | 0,004 | 0,004 | 0,004 | 0,004 |
| | | | | **Co** | | | |
| Initial Analysis | 0,017 | 0,017 | 0,017 | 0,017 | 0,017 | 0,017 | 0,017 |
| Final Analysis | 0,017 | 0,017 | 0,017 | 0,017 | 0,017 | 0,017 | 0,017 |
| | | | | **Bo** | | | |
| Initial Analysis | 0,94 | 0,69 | 0,9 | 1 | 0,92 | 0,71 | 0,89 |
| Final Analysis | 0,96 | 1,03 | 1,01 | 0,98 | 1,04 | 0,88 | 1,1 |
| | | | | **pH** | | | |
| Initial Analysis | 7,21 | 6,58 | 6,44 | 6,47 | 6,77 | 6,45 | 6,6 |
| Final Analysis | 7,77 | 7,16 | 6,77 | 6,46 | 6,14 | 6,02 | 6,08 |
| | | | | **BOD** | | | |
| Initial Analysis | 21 | 19,2 | 18,9 | 11,8 | 13,5 | 7,9 | 0,93 |
| Final Analysis | 0,93 | 0,93 | 0,93 | 0,93 | 0,93 | 0,93 | 0,93 |
| | | | | **COD** | | | |
| Initial Analysis | 45,23 | 37,78 | 40,26 | 21,02 | 22,88 | 16,68 | 6,74 |
| Final Analysis | 20,74 | 13,82 | 13,82 | 6,91 | 13,92 | 1,92 | 6,91 |
| | | | | **Ammonia** | | | |
| Initial Analysis | 0,06 | 0,08 | 0,054 | 0,054 | 0,07 | 0,054 | 0,054 |
| Final Analysis | 0,054 | 0,054 | 0,054 | 0,054 | 0,054 | 0,054 | 0,054 |
| | | | | **Nitrite** | | | |
| Initial Analysis | 0,03 | 0,27 | 0,3 | 0,29 | 0,29 | 0,27 | 0,27 |
| Final Analysis | 0,003 | 0,003 | 0,003 | 0,003 | 0,003 | 0,003 | 0,003 |
| | | | | **Nitrate** | | | |
| Initial Analysis | 14,24 | 14,24 | 14,01 | 13,67 | 13,33 | 13,35 | 12,81 |
| Final Analysis | 68,06 | 68,06 | 24,09 | 16,49 | 16,71 | 14,58 | 14,65 |
| | | | | **TSS** | | | |
| Initial Analysis | 29 | 37 | 12 | 22 | 19 | 33 | 10 |
| Final Analysis | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

*Description: Laboratory Analysis Results*

Good clean water is water that is not excessively polluted by chemicals that are harmful to health, such as Fe, F, Mn, pH, Nitrite ($NO_2$) and Nitrate ($NO_3$), Ammonia, and other chemical substances. The content of chemical substances in water should not exceed the maximum levels permitted according to environmental quality standards. Based on the results of the Wetland water quality analysis, it was found that the values for nitrite, nitrate, and ammonia were far from the maximum levels permitted by referring to Environmental Ministerial Regulation No. 08 of 2009 and Environmental Ministerial Regulation No. 19 of 2010 as well as technical approval S.146/PPM/PPA /PM.2/2/2023, meaning that from these results the quality is still safe, including the water acidity value (pH), where the water pH tends to be close to Neutral with a value range of 6.02-7.77. pH can also be interpreted as the intensity of acidity or alkalinity of a dilute liquid, and represents the concentration of hydrogen ions. On a drinking water scale, the pH contained should be neutral, neither acidic nor alkaline, to prevent the dissolution of heavy metals and corrosion in the distribution of drinking water.

Next, initial analysis of water quality using the SM 23rd Ed method. 5210 B, 2017 to measure BOD, it can be seen that the BOD value between cells in each wetland is different, with a value range from < 0.93 mg/L (outlet) – 21 mg/L (inlet). In contrast to the results of the final analysis, the BOD value seen between cells in each wetland is the same < 0.93 mg/L (Table 8), meaning that the wastewater mostly contains organic carbon which can be degraded with high BOD concentrations and materials that require oxygen. others for oxidation. In wetlands, the carbon cycle is dominated by plants, which starts with the process of growth and nutrient absorption, then they die and finally undergo a degradation process by releasing nutrients, then returning to the soil [30]. The process of degradation and mineralization of organic carbon occurs in the sediment layer and biofilm layer found in plants. In the Free Water Surface (FWS), the loss of concentration of dissolved BOD depends on the growth of microorganisms that attach to the roots, stems, and leaves of plants that have died and fallen into the wetland. If plants cover the entire wetland area, algae usually cannot grow and the main source of oxygen for oxidation reactions comes from reaeration at the water surface and from oxygen translocation to the rhizosphere [31].

The Chemical Oxygen Demand (COD) parameter is the amount of oxygen needed to oxidize organic substances in the water sample; the oxidation uses $K_2Cr_2O_{77}$ which is used as an oxygen source. The COD number is a measure of pollution by organic substances which can naturally be oxidized through microbiological processes and result in a lack of dissolved oxygen in the water. COD is the amount of oxygen in ppm or mg/L that is required under special conditions to chemically decompose organic matter. COD is also a parameter used to determine organic materials in water. COD is the amount of oxygen needed to oxidize materials that can be oxidized by oxidizing compounds, the COD value is a number that can indicate the amount of oxygen needed to oxidize organic materials into $CO_2$ in water with strong oxides in an acidic environment [32]. Measuring the COD value is very necessary, this is because COD can indicate the hardness of wastewater. The standard COD value allowed is in the range of 50 mg/L – 80 mg/L as $O_2$. The results of the initial analysis range of COD values, namely 45.23 mg/L (Inlet) – 6.74 mg/L (outlet). Meanwhile, the final analysis was 11.71 mg/L (Inlet) – < 1.92 mg/L (outlet), and this value experienced a significant decrease when compared with the initial analysis of water quality (Table 8).

**Table 9.** Average removal efficiency for each wetland plant species percell

| Cell | Removal | | | | | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe | Cu | Co | Bo | pH | BOD | COD | NH3 | NO2 | NO3 | TSS | |
| Inlet | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cell 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cell 2 | 41,1 | 0 | 0 | -14,3 | 3,79 | 0,78 | -3,3 | 16,25 | -0,04 | 33,1 | 33,78 | 10,11 |
| Cell 3 | 3,13 | -25 | 0 | -4,07 | 2,06 | 18,78 | 48,9 | 0 | 0,04 | 17 | -41,7 | 1,74 |
| Cell 4 | 30 | 0 | 0 | -3,06 | 0,16 | -7,2 | -55 | -14,81 | 0 | 0,58 | 6,82 | -3,88 |
| Cell 5 | -8,33 | 16,67 | 0 | 19,11 | 3,34 | 20,74 | 56,7 | 11,43 | 0,05 | 6,3 | -36,8 | 8,10 |
| Cell 6 | -7,14 | -25 | 0 | -25,2 | -1,66 | 44,11 | -101 | 0 | 0 | 1,78 | 34,85 | -7,16 |

Boron (Bo) is a non-metallic nutrient that is really needed by plants, one of which is during the generative phase (flowers and fruit). Apart from that, boron also plays an important role in helping the development of new cells, regulating the nutritional balance of plants, and increasing the rate of photosynthesis. Based on the results of the boron content analysis, it can be seen that the boron value in each cell varies, this shows differences in the response to boron needs by each wetland plant planted. The initial analysis of the boron element ranges between 0.69 mg/L – 1 mg/L, and the final analysis of the boron element in each wetland plant planted is also different, the value of the Boron element ranges between 0.88 mg/L – 1.04 mg /L.

The very interesting thing here is the analysis of the heavy metal Iron (Fe) by comparing the results of the heavy metal Fe content analysis at the beginning of the observation and at the end of the observation where there is a decrease in the metal content present, and this occurs in each wetland cell, and the decrease in value varies. between one cell and another cell ranges from 0.06 mg/L to 0.12 mg/L. And this concentration value is still much lower than the maximum permitted content of the heavy metal Fe based on the Minister of Environment Regulation No. 08 of 2009 and Pertek S.146/PPM/PPA/PM.2/2/2023 that for the heavy metal parameter Iron (Fe) the maximum allowable level is 3 mg/L.

### 3.4 Removal analysis

In Table 9 it can be seen that the removal of several analyzed parameters such as Fe, Cu, Co, Bo, pH, BOD, COD, Ammonia, Nitrite, Nitrate, and TSS produces different values.

Several aquatic plants were reported to have absorption levels of the heavy metals Pb, Cr, Cd, Zn, Cu, and Fe with the highest absorption of Fe at 2.63 mg/kg per day [33]. Of the 10 types of aquatic plant species that are most effective as phytoremediation agents for absorbing the heavy metal iron (Fe) are the plants in Cell 2, namely *H. coronarium* and *T.angustifolia* plants and Cell-4 *A. calamus* and *J. effusus* plants, each with removal capabilities. the heavy metal Fe reached 41.07% and 30%. Furthermore, in Cell-3 of the *T. dealbata* and *I. formosona* plants, the average Fe heavy metal removal ability was quite low, namely around 3.13%. In contrast to Cell 5, namely the *C. umbrella* and *C. papyrus* types with a removal percentage of around -8.33% and then Cell-6 with a heavy metal Fe removal capability of -7.14%, meaning that in Cell 5 and Cell 6 there is an addition of heavy metals, This is strongly suspected to be due to the process of re-releasing the heavy metal Fe which was originally bound/stored in plant tissue, but as a result of some of the plants planted dying, the process of releasing the heavy metal Fe back into the cells.

However, in other research show said that the *Cyperus* sp.

has several advantages, some of the advantages of this plant are that it has lots of fibrous roots and is a weed that has the ability to absorb large amounts of nutrients compared to other plants, besides that it can easily grow anywhere, is easy to care for, and is resistant to various external influences [34]. If we compare the water quality analysis at the beginning of the observation with the water analysis at the end of the observation for ammonia levels, there is a decrease in ammonia levels ranging from 11.43% – 16.25%. Meanwhile, nitrite levels experienced a decrease in removal of 0.04% – 0.05%. However, this is in contrast to nitrate levels which experienced a reduction in removal of 0.58% – 33.11%.

In another study, processing liquid waste in constructed wetlands of the Subsurface Flow System type using gravel media for 18 days resulted in a decrease in the concentration of BOD, COD and phosphate in *T. latifolia* plants to 6.19 mg/l each (a decrease of 94 %), 63.04 mg/l (down 76%) and 1.10 mg/l (down 91%), while *Cyperus* sp plants respectively became 4.16 mg/l (down 96%), 60.77 mg/l (down 77%) and 3,588 mg/l (down 72%) [35]. Meanwhile, *T. angustifolia* grows mostly in wetlands, has an aesthetic shape, grows quickly, and has the potential to absorb pollutants. *T. angustifolia* ability to absorb waste containing heavy metals has been reported through phytoextraction, which accumulates in leaf midribs and lamina tissue [36].

Furthermore, in other research, the performance of a constructed wetland planted with *T. angustifolia* with additional atmospheric aeration using a network of perforated pipes in processing influent from Lake Marriott in Egypt overall showed high pollutant removal efficiency, turbidity removal of 98.4%; biochemical oxygen demand (BOD) 83.3%; chemical oxygen demand (COD) 95.8%; NH3-N 99.9%; total nitrogen (TN) 94.7%; $NO_3$-N and $NO_2$-N increased; total P removal (TP) 99.7%, *Vibrio* sp. 100%, *Escherichia coli* 100%; total bacterial count 92.3%; and a 97.5% reduction in anaerobic bacteria [37].

Especially for Co metal, the removal value is 0 in each cell, this shows that the plant's response to a decrease in Co metal levels is very low. Removal of Fe metal as well as a decrease in pH, ammonia, nitrate and the highest TSS values were found in Cell 2 (*H. coronarium* and *T. angustifolia*plants) (Table 9). In another study, it was stated wastewater treatment using a free water surface constructed wetland using the *T. angustifolia* plant resulted in a BOD removal efficiency of 70%, COD of 80%, and TSS of 80%. Meanwhile, using sub-surface flow constructed wetland using *T. angustifolia* plants produces BOD removal efficiency of 80%, COD of 70%, and TSS of 70% [38].

The highest removal of metals Cu and Bo, COD, and nitrite was found in Cell 5 (*P. umbrella* and *C. papyrus* plants). Meanwhile, the highest BOD was found in Cell 6, namely (*I. bicolor* and *N. alba* plants). The selected plants must be resistant to toxicity and changes in the character of incoming wastewater. *C. papyrus* is an aquatic plant found in subtropical and tropical wetlands. This plant has the potential for relatively high biomass production; this is one of the criteria for plants that can be used for constructed wetlands [39].

From the analysis results, the fluctuating and negative removal values can occur and are suspected to be caused by several factors, such as environmental influences from soil composition and vegetation, microbiological processes (nitrification and denitrification), seasonal variations, namely changes in surface runoff and denitrification, as well as plant growth and organic matter decomposition, changes in pH, temperature, and oxygen levels in water. In addition, negative removal values can also occur due to improper sampling and storage, sample preparation, analytical techniques (accuracy and sensitivity of analysis), interference from other elements (using atomic spectroscopy techniques), contamination, and limitations of analytical techniques (detection limits and sensitivity).

In general, wetland plants are able to change pollutant substances to become less or no longer dangerous [40], this is in line with the results of research conducted. The use of aquatic plants is useful for removing, extracting, and detoxifying pollutants from the environment [41]. And furthermore, the difference in removal values shows that the response of each wetland plant planted in each cell is different, because each wetland plant has different genetic characteristics, characters, and plant morphology, so this will influence and determine the growth ability, response and its adaptation to the removal or reduction of existing pollutants.

There are several mechanisms of pollutant absorption by wetland plants, including: 1) Wetland plants have extensive and complex roots that can absorb pollutants from water and soil. The process of root adsorption occurs when pollutants bind to the surface of plant roots [42]. 2) Wetland plants have symbiotic relationships with microorganisms that live on their roots and surrounding areas. These microorganisms can break down pollutants into simpler and harmless compounds [43]. 3) Wetland plants can convert pollutants into gases that can be released into the atmosphere. The process of volatilization occurs when pollutants are converted into more volatile compounds [28]. 4) Wetland plants can use solar energy to break down pollutants. The process of photodegradation occurs when pollutants are converted into simpler and harmless compounds [44]. 5) Wetland plants can absorb pollutant ions from water and soil. The process of ion uptake occurs when pollutant ions bind to the surface of plant roots [45].

## 4. CONCLUSIONS

Based on the results of the analysis of 10 types of wetland plants tested in the field, there are 9 types of plants that have a survival rate of 100%, namely *H. coronarium* J. Koenig), *T. angustifolia*, *I. formosana, T. dealbata, A. calamus, J. effusus, P. umbrela, C. papyrus, D. bicolor*. For the *N. alba* type, the survival rate is 76%, it is suspected that the plant cannot adapt well to local environmental conditions.

Removal of the analyzed parameters such as Fe, Cu, Co, Bo, pH, BOD, COD, Ammonia, Nitrite, Nitrate and TSS produces different values. Especially for Co metal, the removal value is O in each cell. The highest removal of Fe metal (41.07%) as well as a decrease in pH (3.97%), ammonia (16.25%), nitrate (33.11%) and TSS value (33.78%) was found in Cell 2 (*H. coronarium* and *T. angustifolia* plants). Removal of metals, Cu (16.67%) and Bo (19.11%), COD (56.65%), and nitrite (0.05%) were found in Cell 5 (*P. umbrella* and *C. papyrus* plants). Meanwhile, the highest BOD was found in Cell 6, namely (*Iris bicolor* and *N. alba* plants).

The difference in removal values shows that the response of each wetland plant planted in each cell is different, because wetland plants have different genetic characteristics, characters and plant morphology, so this will influence and determine the ability of growth, regeneration, response and its adaptation to the removal or reduction of existing pollutants.

Although this study was conducted on a small scale and was experimental with a short duration, and the results may not be generalizable to a larger scale, the findings can still be applied in the field and used as a reference for the development of actual wetlands at PT. Supreme Energy Muara Laboh. This is because the study was conducted locally and utilized materials available at the location. However, since this study only used a few types of plants, the results cannot be generalized to all types of wetland plants. Therefore, further research is needed on a larger field scale to ensure that the results of this study can be effectively applied to address environmental pollution problems.

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