Resource Recovery Potential of Wastewater Treatment Plants in Yogyakarta

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Abstract. Wastewater contains water, nutrients, and energy resources, which can be recovered for human activities. Product from wastewater is one of the solutions to provide energy and food security amidst the looming energy and fertilizer crisis. Unfortunately, wastewater treatment plants in developing countries are often designed not to accommodate the concept of resource recovery. Currently, there is a real lack of feasibility analysis of upgrading existing wastewater treatment plants to accommodate the concept of resource recovery. Therefore, this study aims to determine the resource recovery potential in existing wastewater treatment plants in Yogyakarta and identify their limitations for resource recovery. Two wastewater treatment plants in Yogyakarta were assessed, one with anaerobic treatment, the other with stabilization ponds. The feasibility is assessed by the parameter of wastewater flow, organics, nutrients, and microbiology compounds. The findings of this study will be beneficial for a regional management standpoint to consider the most suitable strategy for wastewater management in Yogyakarta.

1. Introduction
With an average population growth rate of 2% per year, the population in Indonesia reached 274 million in 2020, and two-thirds of the population is living in urban areas [1]. High population growth and dense area put pressure on environmental quality, food security, and any other resources used for sustaining human life. Wastewater production as a consequence of human activities, is usually seen as a source of pollution. Wastewater has nutrients that contribute to crop growth and improving soil quality [2]. The concept of wastewater resource recovery (WRR) introduces wastewater as a resource that can be converted into valuable material. In addition, the application of the resource recovery introduces circular resource management and circular economy [3].

The indirect use of wastewater for irrigation is more common in developing countries. It is estimated that 1.5 billion people use wastewater with no treatment, and global estimates of the total area irrigated with untreated wastewater range from 3 million to 20 million hectares [4]. This phenomenon cause farmers, vendors, and consumers at a greater risk for excreta-related diseases, which account for one-tenth of the global disease burden. For wastewater treatment plants that have adopted the concept of resource recovery, many of them are mostly focused on waste sludge streams, which are a by-product of biological treatment. Because these streams have relatively low flows in comparison to the main wastewater stream and are more concentrated, resources can be recovered from them with minimal changes to the wastewater infrastructure [5-10].

Therefore, this study aims to study the feasibility of wastewater treatment plants (WWTP or IPAL) located in Special Region fo Yogyakarta to provide resources that can be utilized in the agricultural
sector. Thus, studying the alternative water and other nutrients for fertilizer from WWTP would be beneficial for identifying the potential of these alternative resources in terms of the quantity dan quality of resources to protect the involved human health and the environment. This study selects two treatment systems and compared their potential (treated water) to provide the resources for the agricultural sector.

2. Material and Method

2.1 Wastewater Treatment Plant

Figure 1 depicts a schematic of systems analyzed in this study. There are IPAL Berbah (ABR-Aeration Tank-Wetland) and IPAL Sewon (stabilization pond). Water quality sampling was collected at the inlet and outlet of both systems. All wastewater samples were collected in January-June 2020. The two systems in this study are located within 19 km from each other, at elevations of 65 and 101 m above sea level, in a tropical region with an average annual ambient temperature of approximately 27.2°C. Currently, the stabilization pond system is serving households of approximately 23775 households and will be increasing to 25000 households within the next five years. The Anaerobic Baffled Reactor (ABR)-Aeration Tank-Wetland system is a communal wastewater treatment plant that currently is serving 676 households and projects to serve 700 households in the next five years maximally.

![Diagram](image)

**Figure 1.** Schematic Diagram of (a) the ABR-Aeration Tank-Wetland System; and (b) the Stabilization Pond System.

2.2 Wastewater Treatment Plant

2.2.1 Quantity. Flow measurements are taken in the stabilization pond system during the dry month of May to July 2020. The flow was measured by using the indicator water level. For the ABR-Aeration Tank-Wetland system, flow measurements were taken during the month of April to July 2020. The routine flow measurement was conducted in the inlet of the WWTP while the effluent was rarely measured. In recent months of 2020, the measurement was conducted once in a month. However, the results of effluent measurement show slightly different water levels. It is normal since it is considered a loss due to process, plant adsorption, and evapotranspiration.

2.2.2 Quality. For Stabilization Pond System, grab samples were collected from January to June 2020 during the hours of peak daily flow (between 7:00 a.m. and 10:00 a.m.) and analyzed followed Indonesia National Standard (SNI). The influent and effluent data were collected and measured by different institution. Influent was measured by internal laboratory and it measured pH, temperature, dissolved oxygen, five-days biochemical oxygen demand (BOD₅), Chemical Oxygen Demand (COD) and total suspended solids (TSS) while effluent was measured for BOD₅, COD, TSS, electrical conductivity (EC), Ammonia, Nitrate, Nitrite, Sulfate, Iron, Manganese, Total Chromium and Faecal Coliform.

For ABR-Aeration Tank-Wetland System, grab samples were collected from March, May, and July 2020. The wastewater treatment plant has just been operated for 1.5 years, and water quality monitoring has not yet been conducted every month. The sample was collected during the hours of peak daily flow and analyzed for BOD₅, COD, TSS, TDS, and Ammonia, Phosphate, Nitrate and Nitrite. The pathogenic indicator measurement, such as Faecal Coliform, has just started to be measured but has not been ready
yet when this paper is made. The measurement of pathogenic indicator takes 2-4 weeks, and the appointed laboratory has limited capability to measure all pathogenic indicators.

The type of contaminants in irrigation water mainly depends on where wastewater is generated, i.e., either domestic/municipal [2]. Therefore, the selected wastewater parameters in this study follow the irrigation water standard. The consideration of collecting of nutrient and microbiology data is due to recent spikes in the price of mineral phosphorus (P) is making P recovery an increasingly economically attractive option. Nitrogenous (N) compounds, on the other hand, can be generated from atmospheric nitrogen and are not a limited resource, albeit their production is an energy-intensive process.

The major constraints to wastewater reuse in agriculture are the associated health risks for farmers and consumers [6]. These include excreta-related pathogens, vector-borne pathogens, skin irritants, and toxic chemicals like heavy metals and pesticides [7]. The primary health hazards caused by excreta-related pathogens are diarrhoeal diseases and worm infections. The exposure routes are mainly through contact with wastewater (field workers and nearby communities) and consumption of wastewater-grown produce (produce consumers) [2].

2.2.3 Data Analysis. A mass balance analysis was performed on each system to compensate for the different per capita water usage rates in the two systems. In addition, the removal of water quality parameters are compared as the percent of mass that was removed between the influent and effluent points. For determining the feasibility of effluent water to be reused as irrigation water, the effluent water quality is compared to the standard of irrigation water issue by United States of Environmental Protection Agency (US EPA), Western Australia, Food and Agriculture Organization (FAO), and Government of Indonesia Regulation No. 82/2001

3. Results

In the stabilization pond, the system in flow measurement resulted in average daily flow rates that ranged from 8295.96 m$^3$/day to 15429.84 m$^3$/day. The average per capita flow in this system was 143.7 L/person/day. While the ABR-Aeration Tank-Wetland showed, the average daily flow rate has ranged from 599.45 m$^3$/day to 1878.23 m$^3$/day. The average per capita flow between January to June 2020 in this system is 253.81 L/person/day. The effluent of the stabilization ponds system ranged from 7975.24 to 15250.87 m$^3$/day. Unfortunately, in ABR-Aeration Tank-Wetland System, the measurement was not continuous. The last effluent flow measurement was in July 2020, resulted in a flow of 1043.36 m$^3$/day.

Table 1 shows the removal efficiency of IPAL Berbah (ABR-Aeration Tank-Wetland) and IPAL Sewon (stabilization pond). The observed removal of BOD$_5$, COD, TSS, TDS, and ammonia was better in the stabilization pond system. The removal of BOD$_5$ was higher than 80% for all parameters above except the TDS. On the other hand, the ABR-Aeration Tank-Wetland system has a removal percentage of around 70% for BOD$_5$ and even lesser for TSS removal (40%). Ammonia removal in IPAL Berbah was increased in the effluent. It might seem due to the indicator ponds, which has fish as bioindicators parameter. The removal of pathogenic bacteria of Faecal Coliform was very high in the stabilization ponds system since it has two disinfection methods; they are maturation ponds and chlorine disinfection. Unfortunately, the ABR-Aeration Tank-Wetland system has not measured the concentration of pathogenic bacteria yet. Thus, it could not be compared between the two systems.

Some parameters were measured in the stabilization pond system but not in the ABR-Aeration Tank-Wetland system. The average of sulfate removal efficiency in six times measurement was 24%; iron and manganese have higher removal efficiency, which achieves 97% and 70% for iron and manganese, respectively. However, the total chromium increased its concentration in effluent up to 43% higher than influent. On the other hand, the ABR-Aeration Tank-Wetland system measured several parameters that have not been measured by the stabilization pond. The removal efficiency of phosphate, nitrate, and nitrite was 22%, 37%, and 71%, respectively. These parameters are related much to the observed parameter for irrigation water.


| Parameter   | % Removal | Parameter   | % Removal |
|-------------|-----------|-------------|-----------|
| IPAL Berbah | IPAL Sewon | IPAL Berbah | IPAL Sewon |
| BODs        | 73.77%    | Nitrate     | 37.50%    |
| COD         | 70.78%    | Nitrite     | 71.43%    |
| TSS         | 41.61%    | Sulfate     | -         |
| TDS         | 1.98%     | Iron        | 97.00%    |
| Detergent   | 12.88%    | Manganese   | 70.56%    |
| Ammonia     | -38.31%   | Total Coliform | -   |
| Phosphate   | 22.22%    | Faecal Coliform | -   |

4. Discussion

Based on the results above, the stabilization pond has provided a better removal of BODs, COD, TSS, and TDS than the system of ABR-Aeration Tank-Wetland over the observed months. At the same time, this apparent difference inconsistency may be a result of the different per capita flow rates (and wastewater strengths). The apparent difference in the observed per capita flow rates may be explained by the fact that water supply in the ABR-Aeration Tank-Wetland community pay based on house occupancy. In contrast, customers in the stabilization pond system pay a flat monthly rate regardless of use.

Eutrophication potential is also an important factor for wastewater management in developing countries, and in this study, wastewater reuse would decrease eutrophication potential by discharging high nutrient loads directly to land and river. The ABR-Aeration Tank-Wetland system discharges high concentrations of ammonia (25.7 mg/L) and phosphate 3.43 mg/L) to a receiving water body, which is a local source for fishing. The concentrations discharged by the stabilization pond discharge much lesser ammonia three ±3 mg/L, while phosphate was not measured. Limited nutrient removal is uncommon in the ABR-Aeration Tank-Wetland system, as depicted in Table 1. For example, in a study of 178 different ponds [4] reported removals of only 72% and 68% for total Kjeldahl nitrogen (TKN) and total phosphorus (TP). For a compliance-based approach to effectively manage the discharge of nutrients to receiving waters, communities in developing countries with these existing technologies would have to retrofit their systems to add additional nutrient removal components, which would require additional financial, complexity, energy, and material inputs. However, if effluents are applied to land, reclaimed nutrients can offset farmer's costs for fertilizer or may even augment production capacity. In fact, the phosphorus in human waste alone accounts for one-fifth of the global demand [8]. The existence of pathogens in the system effluents will offset the advantages of nutrient and water recovery due to issues of public health risks. Assessing the potential health risks from pathogenic microbes is particularly important in these settings due to high incidence rates. Unfortunately, only limited pathogenic indicators were measured for routine measurement. It is usually only Faecal coliform, total coliform, and e.coliform that measured in the effluent of the treatment system. In fact, some pathogen protozoa such as Giardia cysts and Cryptosporidium oocysts, helminths, and some nematode eggs are potentially causing health problems to the farmer, plant operator, and the people in the surrounding environment which use the reclaimed water.

Table 2 depicts the comparison between the effluent of two systems and the standard issued by the Government of Indonesia Regulation, US. EPA, Western Australia, and FAO. Despite the observed difference in effluent concentrations, the mass discharge rate of nutrients per capita in the effluent of both systems is not significantly different. The regulation from the Indonesia Government divides the water quality into four classes, in which class 2 and class 3 are intended for the irrigation water. However, in class 2, reused water can also be utilized for the recreation facility. According to the analysis results, both the effluent concentration is more compliant to class 3 standard rather than class 2. The parameter of BODs and Nitrate is found to be exceeded the Indonesia regulation. According to US EPA, the effluent of the treatment system complies with the use of reclaimed water in non-potable applications in municipal settings where public access is not restricted. According to the Western
Australia Standard, the water quality produced from the treatment can be used either for subsurface and surface irrigation. Based on the FAO, the effluent is more suitable for agricultural purposes with slight to moderate restriction on use. Therefore, it can be concluded that the use of effluent water from both systems is actually feasible to be used as irrigation water. However, the chlorine concentration on the effluent has to be controlled so that it will not affect the plant's growth.

However, the feasibility of wastewater products should not only be measured through the quantity and quality of wastewater, but it is also essential to include the study of their impact on the production of wastewater products (treated wastewater and sludge). The study of LCA (Life Cycle Assessment) and LCC (Life Cycle Cost) are required to assess the environmental and economic feasibility [9, 10]. Further research on impact assessment would be carried out in the future.

Table 2. The comparison between the effluent of two systems and the standard issued by the Government of Indonesia Regulation, US. EPA, Western Australia, and FAO

| Parameter       | Unit | Effluent | Standard          | IPAL Berbah Sleman | IPAL Sewon Bantul | US.EPA | Western Australia | FAO |
|-----------------|------|----------|-------------------|--------------------|-------------------|--------|-------------------|-----|
|                 |      |          | PP 82/2001        | Class 2            | Class 3           | Unrestricte d | Resricte d | Subsurfac e irrigation | Surface irrigatio n | Degree of Restriction on Use | Non e | Slight to Moderat e | Sever e |
| BOD₅            | mg/L | 4.75     | 9.03              | 3                  | 6                 | ≤10          | ≤30        | <20          | <20                      | <450 | 450-2000 | >2000 |
| COD             | mg/L | 20.65    | 27.40             | 25                 | 50                |              |            |              |                          | 0.5  | 0.5      |       |
| TSS             | mg/L | 5.5      | 9.17              | 50                 | 400               | ≤30          | <30        | <30          |                          | 0.2  | 0.2      |       |
| TDS             | mg/L | 254.5    | 557.67            | 1000               | 1000              |              |            |              |                          | <450 | 450-2000 | >2000 |
| Detergent       | mg/L | 0.0828   | 1.2012            | 200                | 200               |              |            |              |                          | 6.5  | 6.5-8.5  | 6.5-8.6 |
| Temperature     | ºC   | 26.3     | 26.53             |                    |                   |              |            |              |                          |      |          |       |
| pH              |      | 7.55     | 7.70              | 6-9                | 6-9               | 6-9          | 6-9        | 6.5-8.4      |                          |      |          |       |
| EC              | µmhos/cm | 6.3258 | 525.33            |                    |                   |              |            |              |                          |      |          |       |
| Ammonia         | mg/L | 2.80     | 1.91              |                    | -                 | -            | -          | 0.5          | 0.5                                    |
| Phosphate       | mg/L | 0.5      | 0.2               | 1                  |                   |              |            | 0.2          | 0.2                                    |
| Nitrate         | mg/L | 2.00     | 26.54             | 10                 | 20                |              |            | <5           | 5 - 30                                  |
| Nitrite         | mg/L | 1.61     |                   | 0.06               | 0.06              |              |            |              |                          | 5    | 5-30     | >30   |
| Sulfate         | mg/L | 57.00    |                   | -                  | -                 |              |            |              |                          |      |          |       |
| Iron            | mg/L | 0.2353   |                   |                    |                   |              |            |              |                          |      |          |       |
| Manganese       | mg/L | 0.5951   |                   |                    |                   |              |            |              |                          |      |          |       |
| Total Chromium  | mg/L | 0.0222   | 0.05              | 0.05               |                   |              |            |              |                          |      |          |       |
| Fecal Coliform  | MPN/100 ml | <1.8  | 5000               | 1000               | 0                  | Not detectable | ≤200       |              |                          |      |          |       |
| Total Chlorine  | mg/L | 0.017    |                   | 1                  | 1                 |              |            |              |                          |      |          |       |
| Free Chlorine   | mg/L | 0.03     | 0.03              |                    |                   |              |            |              |                          |      |          |       |
5. Conclusion
Wastewater treatment plants in developing countries typically have not been oriented to reuse their effluent but only discharge to receiving water body, which potentially causes eutrophication. This study assesses the feasibility of two wastewater treatment systems in Yogyakarta to provide water and nutrient for agriculture. According to the results, the effluent from both systems has complied the class 3, government regulation of PP No. 82/2001. Compared to other international standards, the effluent from both systems can be used for slight to moderate restriction of surface irrigation. In addition, the standard from USE EPA has classified the effluent water that can be used as unrestricted irrigation. This research would be a benefit for stakeholders involved in wastewater management to consider a wastewater product as one of the alternative resources to supply water for agricultural purposes. Hence, the use of alternative resources could reduce the amount of natural resources used in agriculture.

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