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Evaluation of Domestic Wastewater and Constructed Wetland Treatment in Residential Areas

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Abstract

Domestic wastewater management in developing countries frequently faces challenges due to limited sanitation infrastructure, resulting in environmental pollution and public health risks. Constructed wetland (CW) technology, a nature-based solution that utilises vegetation to filter and decompose pollutants, offers a promising alternative. This study aims to design a domestic wastewater treatment plant (WTP) using a combined CW system, which includes an equalisation tank, a sedimentation tank, and a subsurface flow constructed wetland (SFCW). The case study was conducted in Lam Trieng Madani Housing, Aceh Besar Regency, which lacks adequate wastewater treatment facilities. Laboratory analyses revealed that the Total Suspended Solids (TSS) and total coliform levels in domestic wastewater exceeded the thresholds of Indonesian Regulation No. 68/2016 from the Ministry of Environment and Forestry. The proposed WTP with combined CW technology is expected to offer an effective solution for reducing domestic wastewater pollution in the area. Furthermore, the study contributes to the development and implementation of CW-based treatment systems, serving as a model for other residential areas with similar conditions. This approach supports the creation of sustainable, efficient, and environmentally friendly wastewater management systems, in line with Sustainable Development Goal (SDG) 6, which aims to ensure the availability and sustainable management of water and sanitation for all.

Article Info	Keywords
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	Total coliform

1. Introduction

Domestic wastewater management is a global issue that is increasingly receiving attention, particularly in developing countries, where sanitation infrastructure remains limited. Domestic wastewater, comprising black water (waste from toilets) and grey water (waste from household activities such as bathing, laundry, and cooking), has the potential to pollute the environment if not appropriately managed [1–4]. According to a 2019 United Nations (UN) report, approximately 80-90% of wastewater

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in developing countries is discharged directly into the environment without adequate treatment, thereby increasing the risk of groundwater and surface water pollution [5–7]. Pollutants in domestic wastewater, such as total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia, oil and fat, and coliform, can disrupt the balance of aquatic ecosystems and pose health risks to the community [8–10]. Therefore, the development of effective, environmentally friendly, and low-cost wastewater treatment technology is a pressing need to enhance the quality of sanitation in residential areas.

Various regulations have been issued to regulate domestic wastewater quality standards, one of which is the Minister of Environment and Forestry Regulation of the Republic of Indonesia Number 68 of 2016, which sets the threshold for pollutant parameters before wastewater can be discharged into the environment [11]. However, in many settlements, wastewater treatment is still carried out conventionally using septic tanks or cubluks, which are not always able to reduce pollutant levels to meet quality standards [12,13]. In some areas, grey water is even directly discharged into drainage or open land, which causes degradation of surface water quality and contributes to the spread of pathogens that are harmful to public health [14–16]. In this context, a treatment system is needed that can effectively treat wastewater, with low investment and operational costs, and does not require high technical expertise in its operation.

One of the promising alternative technologies in domestic wastewater treatment is the Constructed Wetland (CW). CW is a vegetation-based treatment system that mimics natural processes in wetland ecosystems, filtering and decomposing pollutants through the interaction of microorganisms, filter media, and aquatic plants [17]. CW has been widely used in various wastewater treatment applications, including for domestic waste, agricultural waste, industrial waste, and landfill leachate treatment [18]. The advantages of CW compared to conventional technologies include high effectiveness in removing organic and inorganic pollutants, ease of maintenance, and high energy efficiency [19]. Additionally, CW can be combined with other supporting systems, such as equalisation tanks and sedimentation tanks, to enhance pollutant removal efficiency and prevent clogging of the filter media [20].

Based on the configuration of wastewater flow, CW is divided into two main types: Free Water Surface Constructed Wetland (FWSCW) and Subsurface Flow Constructed Wetland (SFCW) [21]. FWSCW has water flow above the surface of the media and is therefore more susceptible to odour and the presence of disease vectors, such as mosquitoes. Meanwhile, SSFCW has water flow below the surface of the filter media, which makes it more effective in reducing odour, preventing direct contact between wastewater and humans, and increasing pollutant removal efficiency [22]. Previous studies have shown that SSFCW has a TSS removal efficiency of up to 97%, a BOD of 59.0-93.3%, a COD of 50.7-95.2%, and a nitrate removal of up to 85.4%.

Although CW has been widely applied, several challenges remain, particularly related to the risk of filter media clogging due to the accumulation of suspended particles in wastewater. To overcome this problem, several studies recommend the use of equalisation tanks and sedimentation tanks before wastewater enters the CW unit [23]. The equalisation tank functions to standardise the discharge and sewage concentration, thereby reducing fluctuations in the pollutant load entering the CW [24]. Meanwhile, the sedimentation tank plays a crucial role in settling suspended particles, thereby significantly reducing the TSS load entering the CW [25]. The combination of equalisation tanks, sedimentation tanks, and SSFCW has been demonstrated to enhance the efficiency of wastewater treatment and prolong the operational lifespan of the filter media in the CW system [26].

In this study, CW Combination is proposed as a solution for domestic wastewater treatment in Lam Trieng Madani Housing, Aceh Besar Regency, which currently lacks an adequate wastewater treatment system. The results of laboratory tests on domestic wastewater at the research location showed that the TSS parameters (46 mg/L) and total coliform (53,333 counts/100 mL) exceeded the quality standards set by PerMenLHK No. 68 of 2016 [27]. Therefore, the planning of the WWLD system with CW Combination technology, consisting of an equalisation tank, sedimentation tank, and SSFCW, is

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expected to be an effective solution to overcome environmental pollution caused by domestic wastewater in this area.

Domestic wastewater in Lam Trieng Madani Housing, Kuta Baro, Aceh Besar, is only collected in a cubicle or directly channelled into the drainage. Based on PerMenLHK No. 68 of 2016 concerning Domestic Wastewater Quality Standards, domestic wastewater from households has the potential to pollute the environment; therefore, it needs to be treated before being discharged into the atmosphere [28]. Faecal sludge is a source of pollution consisting of solids dissolved in water, most of which contain organic material. To process the faecal sludge produced from the local system, a Faecal Sludge Treatment Installation (FSTI) unit is needed, which will accommodate and process the faecal sludge from the community's septic tanks [28].

Specifically, this study aims to (i) identify the characteristics of domestic wastewater in Lam Trieng Madani Housing, (ii) design a WWTP system with CW Combination technology that follows the characteristics of existing wastewater, and (iii) calculate the estimated cost of building this WWTP system. The novelty of this study lies in the combination of SSFCW technology with equalisation tanks and sedimentation tanks, adapted explicitly for residential environments with limited sanitation infrastructure. In addition, this study provides an estimate of the construction cost (RAB) for a CW-based wastewater treatment system, which can serve as a reference for implementation in other locations with similar characteristics.

Thus, the results of this study are expected to contribute to the development of a sustainable domestic wastewater treatment system with an effective, efficient, and environmentally friendly nature-based technology approach. This study also provides a basis for decision-making in settlement-based sanitation planning, which can support the achievement of Sustainable Development Goal (SDG) 6, namely ensuring the availability and management of clean water and sustainable sanitation for all. Therefore, SSFCW is a more suitable choice for implementation in residential areas.

2. Methodology

This study aims to design a Domestic Wastewater Treatment Plant (DWTP) utilising a combination of Constructed Wetland (CW) technology, which consists of an equalisation tank, sedimentation tank, and Subsurface Flow Constructed Wetland (SSFCW). The research methodology includes several main stages: identification of domestic wastewater characteristics and design of the DWTP system. The initial stage of the study involved identifying the characteristics of domestic wastewater in Lam Trieng Madani Housing, Aceh Besar Regency. Wastewater samples were collected from household drains and analysed in the laboratory to measure water quality parameters, including Total Suspended Solids (TSS) and total coliform counts. This analysis aims to determine the extent to which these parameters exceed the quality standards set out in the Regulation of the Minister of Environment and Forestry No. 68 of 2016 concerning Domestic Wastewater Quality Standards. Based on the results of the wastewater characteristic identification, the next step is to design an appropriate WTP system. The proposed system comprises three main components: an equalisation tank, a sedimentation tank, and SFCW.

Table 1. Data Collection Approach

No.	Data	Source	Method
1	Characteristics of domestic wastewater	Laboratory test results	On-site sampling, lab testing, and taking average values of samples for each parameter
2	Land Conditions at Planning Location	Location survey and *Google Earth Software*	Land measurement through applications and direct location observation

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No.	Data	Source	Method
3	Domestic wastewater quality standards	Regulation No. 68 of 2016 concerning Domestic Wastewater Quality Standards	Internet search
4	Planning literature	Books and previous research	Internet search

The following is a research framework presented in the form of a flowchart, starting from identifying the problem, searching for various literature studies related to the literature review, collecting the necessary data, processing the data, and designing the CW Combination WTP.

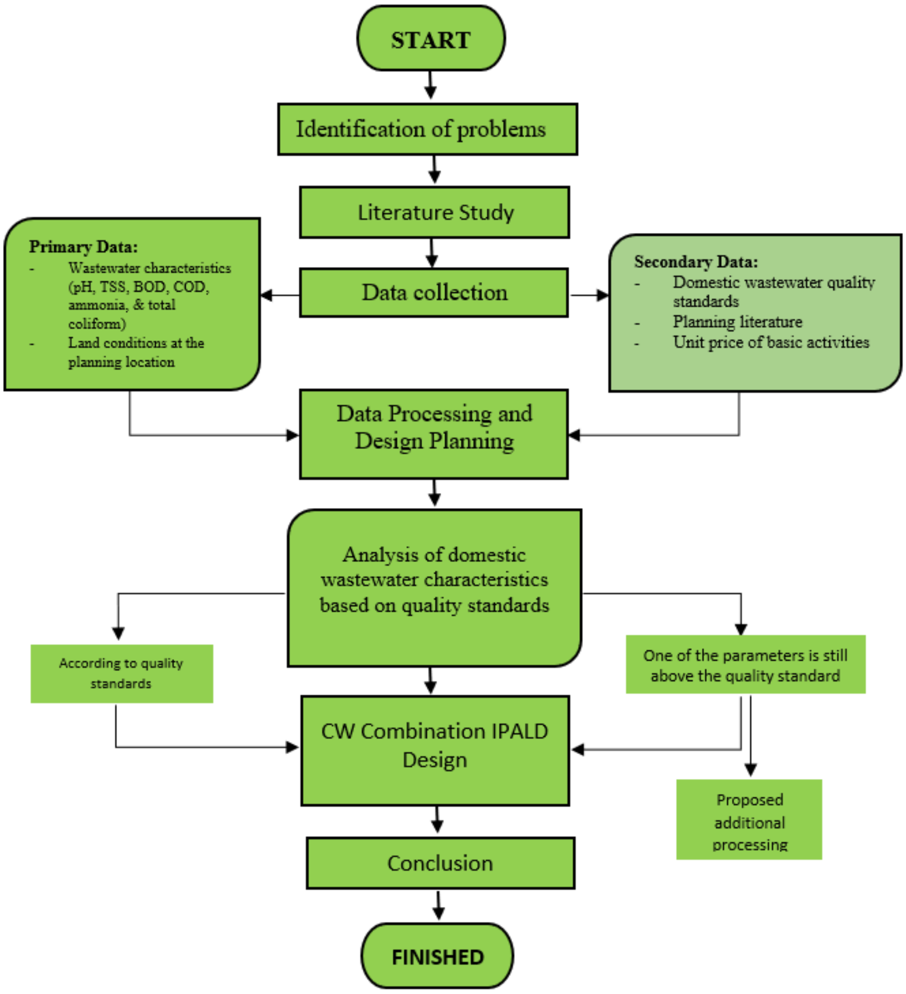

Figure 1: Research flowchart

3. Result & Discussion

Domestic wastewater management is a significant concern in developing countries, including Indonesia, as limited sanitation infrastructure can lead to environmental pollution and health risks. Domestic wastewater, which consists of *black water* (waste from toilets) and *grey water* (waste from household activities such as bathing, washing clothes, and cooking), contains pollutants such as total suspended solids (TSS), *biochemical oxygen demand* (BOD), *chemical oxygen demand* (COD), ammonia, oil and fat, and coliform. These pollutants can disrupt aquatic ecosystems and pose health risks if not managed properly. A 2019 United Nations (UN) report stated that around 80-90% of

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wastewater in developing countries is discharged directly into the environment without adequate treatment, increasing the risk of groundwater and surface water pollution.
The samples taken consisted of three homogenised domestic wastewater, black water, and grey water samples from three twin cubicles in residents' houses, which were able to represent the quality of domestic wastewater in Lam Trieng Madani Housing. The results of the laboratory tests are presented in **Figure 2** below.

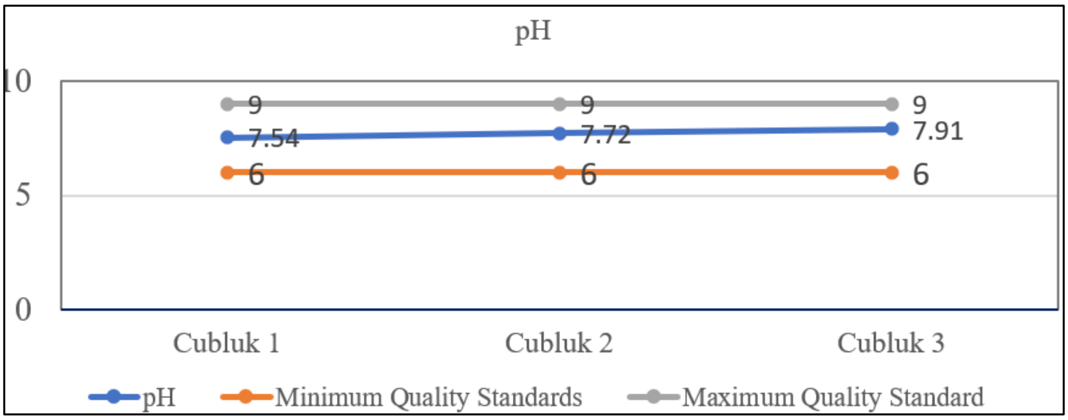

Figure 2: Laboratory Test Results on pH Parameter Samples

Figure 2 is a graph showing the pH values at three measurement points called "Cubluk 1", "Cubluk 2", and "Cubluk 3". This graph also compares the pH values with the minimum and maximum quality standard limits. Showing the pH values measured at each point, Cubluk 1 is 7.54, Cubluk 2 is 7.72, and Cubluk 3 is 7.91. The pH tends to increase from Cubluk 1 to Cubluk 3. There are no points that exceed the maximum limit or fall below the minimum limit, so the water at this location meets the specified pH standards.

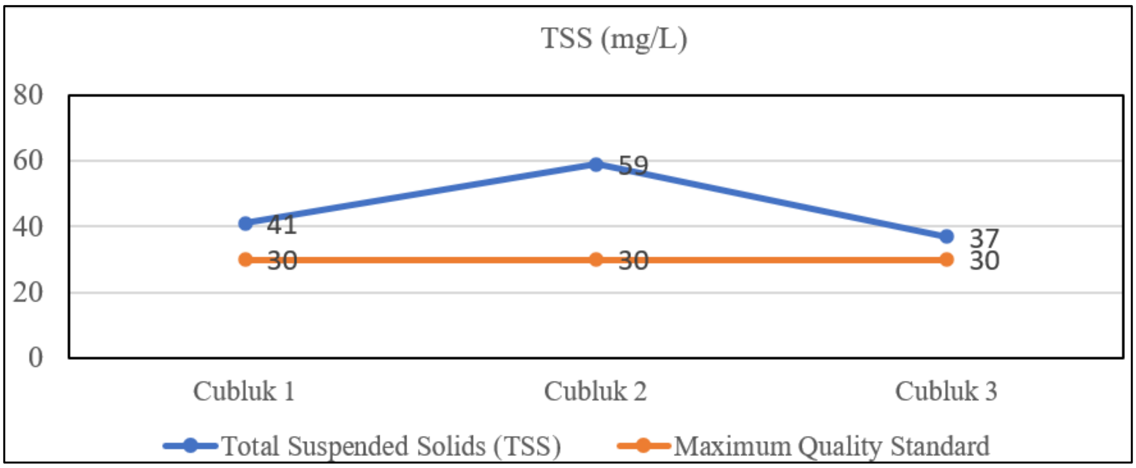

Figure 3: Laboratory Test Results on TSS Parameter Samples

Figure 3 shows the Total Suspended Solids (TSS) levels in mg/L at three measurement points, labelled "Cubluk 1", "Cubluk 2", and "Cubluk 3", which display the TSS levels detected at each point. Cubluk 1 is 41 mg/L, Cubluk 2 is 59 mg/L (highest), and Cubluk 3 is 37 mg/L (lowest), with the maximum TSS limit allowed, which is 30 mg/L. All points exceed the maximum quality standard (30 mg/L), meaning that the water quality does not meet the required standards for TSS. TSS increased significantly at Cubluk 2 (59 mg/L), then decreased at Cubluk 3 (37 mg/L). The increase in TSS at Cubluk 2 could be attributed to specific activities or sources of pollution in the area. The decrease in TSS at Cubluk 3 indicates a sedimentation process or deposition of suspended particles. Management actions, such as filtering or sedimentation, are needed to reduce TSS levels and meet quality standards.

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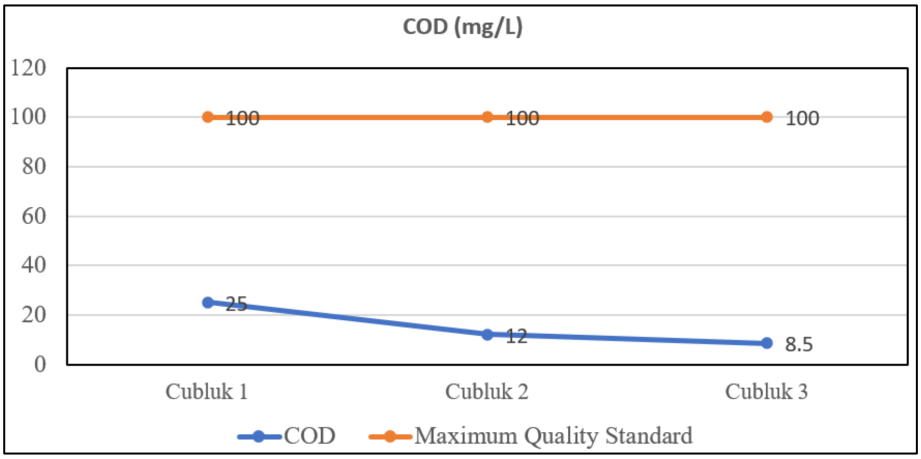

Figure 4: Laboratory Test Results on TSS Parameter Samples

Figure 4 is a graph showing the levels of Chemical Oxygen Demand (COD) in mg/L at three measurement points compared to the maximum quality standard of 100 mg/L. The COD levels detected at each point are as follows: Cubluk 1 at 25 mg/L, Cubluk 2 at 12 mg/L, and Cubluk 3 at 8.5 mg/L. All COD values are far below the maximum quality standard (100 mg/L), indicating that the water quality related to COD is safe and meets the standards. COD has decreased gradually from Cubluk 1 to Cubluk 3. This decrease in COD indicates that the natural process or water treatment system is working effectively, reducing the content of organic materials that can pollute the water.

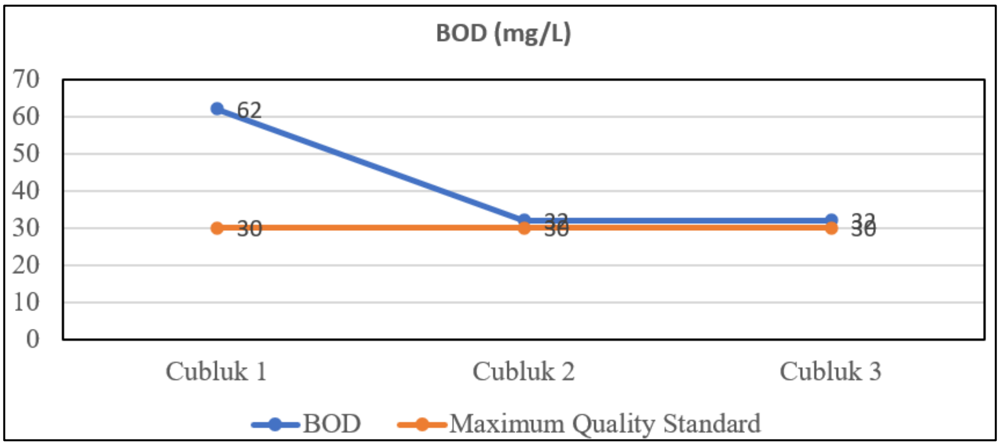

Figure 5: Laboratory Test Results on BOD Parameter Samples

Figure 5 is a graph showing the Biochemical Oxygen Demand (BOD) levels in mg/L at three measurement points compared to the maximum quality standard of 30 mg/L. The BOD levels detected at each point are as follows: Cubluk 1 at 62 mg/L (exceeding the quality standard), Cubluk 2 at 30 mg/L (in accordance with the quality standard), and Cubluk 3 at 30 mg/L (following the quality standard). Cubluk 1 has a very high BOD level (62 mg/L), far above the quality standard (30 mg/L). This indicates high organic pollution at this point. Cubluk 2 and Cubluk 3 have BOD levels that follow the quality standard (30 mg/L), indicating a decrease in BOD after Cubluk 1. The significant reduction from Cubluk 1 to Cubluk 2 indicates an effective natural treatment or recovery process that reduces dissolved organic matter, which can cause oxygen deficiency in water. Further investigation is needed in Cubluk 1 to identify the source of organic pollution that causes high BOD. If Cubluk 1 is part of a wastewater treatment system, then the initial treatment efficiency needs to be increased to reduce the organic load

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before reaching the next point. Periodic monitoring is still necessary to ensure that the BOD levels in Cubluk 2 and Cubluk 3 remain stable within the permitted limits.

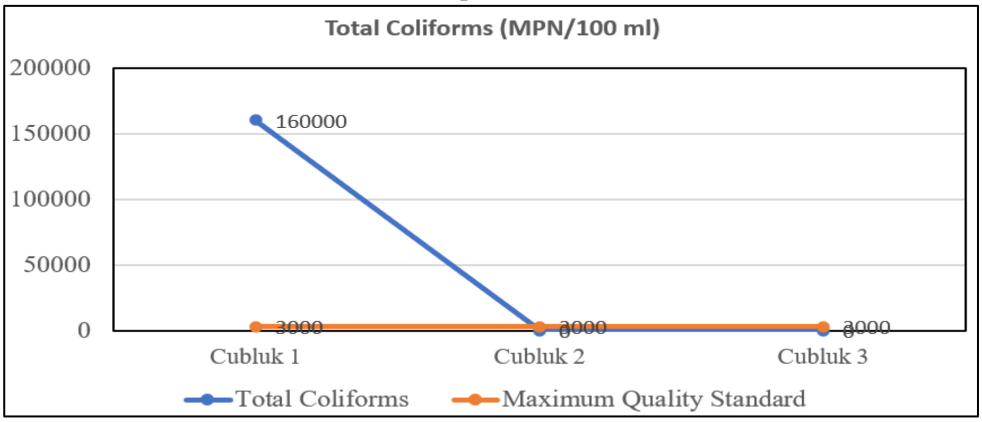

Figure 6: Laboratory Test Results on Total Coliform Parameter Samples

Figure 6 is a graph showing the number of Total Coliform in MPN/100 ml at three measurement points (Cubluk 1, Cubluk 2, and Cubluk 3) and its comparison with the maximum quality standard of 3,000 MPN/100 ml. The number of coliforms detected at each point was Cubluk 1 of 160,000 MPN/100 ml (very high, far above the quality standard). Cubluk 2 of 3,000 MPN/100 ml (following the quality standard), and Cubluk 3 of 3,000 MPN/100 ml (following the quality standard). Cubluk 1 has a very high number of Total Coliforms (160,000 MPN/100 ml), far exceeding the quality standard (3,000 MPN/100 ml). This indicates very severe bacterial contamination, possibly originating from domestic or industrial waste that has not been adequately processed. Cubluk 2 and Cubluk 3 have Total Coliform counts that meet the quality standards (3,000 MPN/100 ml). There was a drastic decrease from Cubluk 1 to Cubluk 2, which could indicate a processing process or natural factors that are very effective in reducing the number of bacteria.

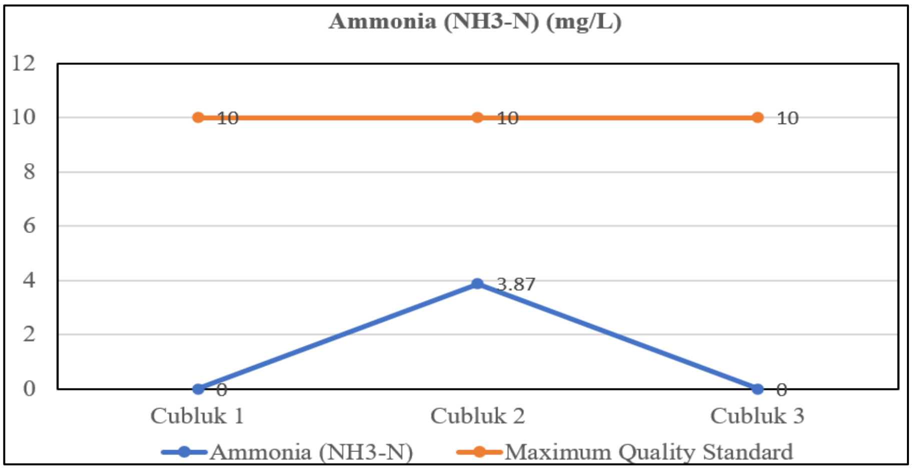

Figure 7. Laboratory Test Results on Ammonia Parameter Samples

Figure 7 shows a graph of Ammonia (NH_3-N) levels in mg/L at three measurement points (Cubluk 1, Cubluk 2, and Cubluk 3) and their comparison with the maximum quality standard of 10 mg/L. The ammonia levels detected at each point showed that Cubluk 1 was 0 mg/L (not detected), Cubluk 2 was 3.87 mg/L (below the quality standard), and Cubluk 3 was 0 mg/L (not detected). Ammonia levels at all points were still far below the maximum quality standard (10 mg/L), so they were safe. Cubluk 1 and Cubluk 3 had ammonia levels of 0 mg/L, indicating that there was no or very little ammonia contamination at these points. Cubluk 2 experienced an increase in ammonia to 3.87 mg/L, but remained

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below the permitted threshold. This may have been a temporary source of ammonia, which then decreased or decomposed in Cubluk 3. Routine monitoring is still necessary to ensure that ammonia levels remain stable and do not exceed the quality standard. If the increase in ammonia in Cubluk 2 is repeated or continues to increase, it is necessary to identify the source, such as domestic or industrial waste. Ensure that the waste processing process continues to run optimally, so that ammonia levels remain within safe limits.

4. Conclusion

Based on the results of laboratory tests, the results of the TSS and *total coliform parameter tests* exceeded the maximum levels of domestic wastewater based on PerMenLHK No. 68 of 2016 concerning Domestic Wastewater Quality Standards, that domestic wastewater produced from households, businesses or activities has the potential to pollute the environment, so wastewater treatment is needed before being discharged into the environmental media. Based on this, domestic wastewater treatment using a combination of CW is necessary to reduce the parameter values so that they do not exceed the maximum levels of domestic wastewater quality standards set, ensuring it is safe if released into the environment.

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