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The Effectiveness of *Pseudomonas aeruginosa* in Degrading Biochemical Oxygen Demand and Chemical Oxygen Demand in Small Island Domestic Wastewater

Nurdianti[1], Agus Bintara Birawida[1]†, Hasnawati Amqam[1], Gurendro Putro[2] and Shaharuddin Mohd Sham[3]
[1]Department of Environmental Health, Faculty of Public Health, Hasanuddin University, Makassar, Indonesia
[2]Research Center for Public Health and Nutrition, National Research and Innovation Agency, Jakarta, Indonesia
[3]Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Selangor, Malaysia
†Corresponding author: Agus Bintara Birawida; agusbirawida@unhas.ac.id

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ABSTRACT

The high organic content of domestic wastewater on small islands increases the risk of environmental pollution and disease spread. Limited resources and infrastructure exacerbate waste management challenges in these regions. This study aimed to identify local bacteria from domestic wastewater and test the effectiveness of *Pseudomonas aeruginosa* in degrading BOD and COD. This study was conducted in the Spermonde Islands of Makassar City. Wastewater samples were collected from six locations and analyzed using MALDI-TOF MS. Effectiveness tests were carried out in a simple 5 L ex situ bioreactor using a completely randomized design (CRD) with two factors: bacterial inoculum concentration (0%, 5%, 10%, and 15%) and incubation time (2, 4, 6, and 8 days). *Pseudomonas aeruginosa* effectively reduced BOD and COD by 64–77% and 63–77%, respectively. Variations in inoculum concentration did not significantly affect BOD and COD reduction ($p > 0.05$), whereas incubation time had a significant effect ($p < 0.05$). The highest removal efficiency was observed on day 6. These findings suggest that optimizing the incubation time is more critical than increasing the inoculum concentration for successful bioremediation. Pseudomonas aeruginosa is a practical and economical option for supporting sustainable wastewater management on small islands and can be integrated into household-scale communal wastewater treatment plants (WWTPs) to improve treatment effectiveness.

INTRODUCTION

Small islands have a wide range of defined problems (Khotimah et al. 2021, Singh et al. 2022). Ecologically, these islands are fragile and vulnerable due to limited land area, scarce resources, restricted distribution, and high isolation, which places them at high risk (Kumar & Mishra 2024). These factors increase the vulnerability of island communities to disease and mortality, often linked to inadequate sanitation (Birawida et al. 2020).

Population growth increases the environmental pressure. Unlike solid waste, which is often managed, domestic wastewater is frequently discharged directly into waterways and can pollute coastal and groundwater environments (Harahap et al. 2021). Rivers, lakes, and ponds are the most vital and vulnerable freshwater systems, playing a crucial role in sustaining all forms of life (Kumar & Mishra 2024).

Wastewater commonly contains excreta and greywater from kitchens and bathrooms, and is rich in organic materials (Buslima et al. 2024, Rahma & Purwanti 2020). Millions of intestinal bacteria and a small number of other organisms are found in domestic waste, posing a danger to the residents. Laundry wastewater, which is rich in detergents, phosphates, and nitrates, produces foam and is harmful to aquatic organisms in freshwater ecosystems through eutrophication. Domestic wastewater production accounts for 70–75% of the total waste production. Domestic wastewater has a large volume, contributing to water body pollution by approximately 70–80% (Khotimah et al. 2021).

Domestic wastewater is a significant problem in Indonesia, especially in the archipelago, which is home to approximately 60% of the country's 250 million people. Population growth has led to increased waste production, which has impacted the environmental quality. Most communities continue to use rivers, seas, and beaches as disposal sites (Prastiwi & Rosariawari 2023). Therefore, treatment is required to ensure that domestic wastewater is safely discharged into the environment. Conventional biological treatment methods can meet emission standards but have limitations such as high costs, large land area requirements, complexity, high energy needs, and costly maintenance (Bai et al. 2024, Rafiaee et al. 2020, Xiao et al. 2021).

Therefore, simpler and lower-cost alternatives are required. One promising approach is bioremediation using local microorganisms to degrade pollutants to environmentally safe concentrations (Vasdravanidis et al. 2022). Bioremediation is inexpensive and uses natural microbial activity without causing significant side effects during the treatment process (Shah & Shah 2020).

Fig. 1 shows a map of the relationships between keywords from VOSviewer related to wastewater treatment, bioremediation and microbiology. Keywords are grouped by category with different colors: blue highlights the analysis of waste characteristics and the degradation process by microorganisms, green focuses on the impact of waste and the potential of microorganisms, and red covers technologies to improve treatment efficiency.

Fig. 2 shows the distribution of research by country, indicating that waste treatment and environmental technology issues are global concerns with varying priorities. In line with the keyword map in Fig. 2, research on wastewater bioremediation using BOD- and COD-degrading bacteria has attracted widespread attention. One of the potential

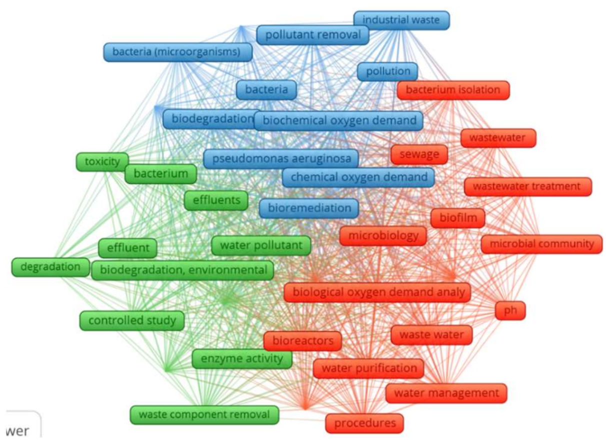

Fig. 1: Keyword network VOSviewer analysis wastewater bioremediation.

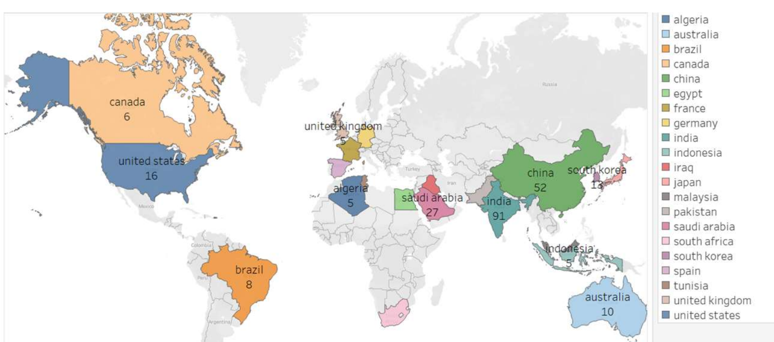

Fig. 2: Global distribution of wastewater bioremediation research by bacteria.

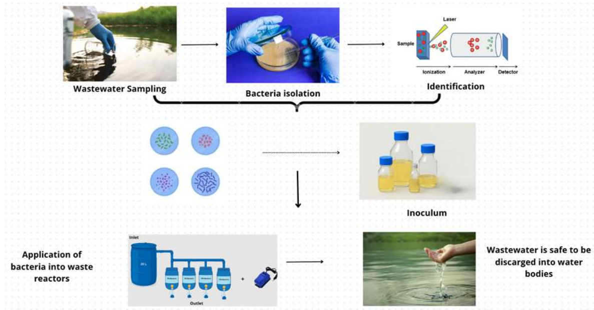

Fig. 3: Research illustration.

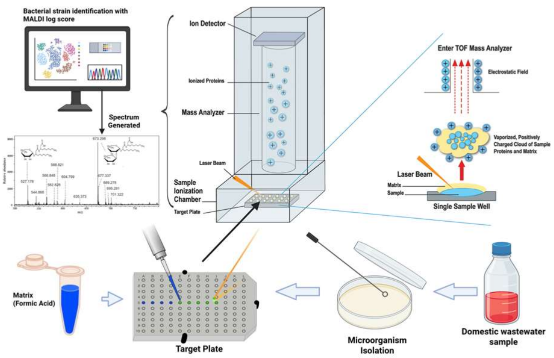

Fig. 4: Illustration of the bacterial identification process using MALDI-TOF MS.

bacteria that has been extensively studied is *Pseudomonas aeruginosa*.

This bacterium can degrade various pollutants found in domestic wastewater. *Pseudomonas aeruginosa* utilizes various carbon and energy sources and has an efficient enzymatic system for degrading pollutants (Lalucat et al. 2020). The environmental characteristics of small islands are marked by limited waste-treatment infrastructure. Although there are communal wastewater treatment plants (WWTPs) on a household scale, these facilities are either not operational or are not utilized optimally. This condition, combined with the vulnerability of water quality to pollution and incidents of seawater intrusion that increase salinity, results in a dynamic environmental system that requires biological agents with high adaptability to remediate.

Pseudomonas aeruginosa is a gram-negative bacterium with broad metabolic flexibility; it can metabolize under both aerobic and anaerobic conditions and tolerate variations in nutrient availability and salinity. In addition to these adaptive abilities, *Pseudomonas aeruginosa* has the capacity for enzymatic degradation of various complex organic compounds, including components of domestic organic matter, thereby potentially reducing measurable organic loads, such as Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD), in domestic wastewater. The combination of these physiological properties and degradation capabilities makes *Pseudomonas aeruginosa* a relevant candidate for bioremediation strategies in wastewater treatment systems that are prone to operational disruptions and the effects of seawater intrusion.

Previous studies have focused on the use of degrading bacteria to treat industrial, textile, and heavy metal waste. However, the potential *of Pseudomonas aeruginosa* to degrade domestic waste, particularly in small island ecosystems, has not been widely explored. Therefore, this study aims to make a new contribution by analyzing the effectiveness *of Pseudomonas aeruginosa* in reducing BOD and COD levels in domestic waste on small islands.

MATERIALS AND METHODS

Research Location

This research was conducted in the Spermonde Islands, Makassar City, South Sulawesi, from August to November 2024. This study focused on domestic wastewater bioremediation using local bacteria. Samples were collected by grab sampling at six observation points selected for their propensity to accumulate domestic waste, limited treatment facilities, and vulnerability of the coastal ecosystem.

Isolation and Identification of Bacteria

The equipment used included filter/filtration sets, membrane paper, TPC, incubators, water baths, tweezers, cotton, Bunsen burners/spirit lamps, test tube racks, Petri dishes, sample bottles, tissues, markers, lighters, paper labels, VITEK MS machines, and VITEK MS test slides (Fig. 3). The materials used included bacterial samples, 70% alcohol, sterile water, masks, gloves, 1 µL tips, VITEK MS-CHCA matrix, nutrient agar (NA), and nutrient broth (NB). Bacterial isolation was performed by filtering 100 mL of domestic wastewater using a 0.45 µm filter membrane, which was then placed on Cn agar medium and incubated at 35°C for 24 h. Bacterial identification was performed using MALDI-TOF Mass Spectrometry by applying bacterial colonies to a target slide coated with VITEK MS-CHCA (α-cyano-4-hydroxycinnamic acid) matrix to facilitate ionization. After drying and crystallization, the slides were analyzed using a VITEK MS integrated with analysis software (Fig. 4) (Izzati 2018).

Culture and Experimental Design

Pseudomonas aeruginosa isolates previously obtained from domestic wastewater were cultured on Nutrient Agar (NA) for 48 h at room temperature. Six colonies were transferred into 200 mL of (NB) and incubated at 110 rpm for 24 h. Inoculum concentrations of 5% (2.5×10^3 CFU), 10% (5×10^3 CFU), and 15 % (7.5×10^3 CFU) were prepared. The experiment used a completely randomized design (CRD) with two factors: inoculum percentage (0%, 5%, 10%, and 15%) and incubation time (2, 4, 6, and 8 days), each with three replicates (Khadijah et al. 2023, Rahardja et al. 2010). The ex-situ bioreactor consisted of four 5-L plastic reactors connected in series. Reactor A served as the control (0% inoculum), and reactors B–D received 5%, 10%, and 15% inoculum, respectively.

Table 1: pH and temperature values.

Time [days]	pH	Temperature [°C]
2	7.74	28.6
4	7.73	28.7
6	7.73	28.8
8	7.73	27.8
Average	7.7	28.4

Physicochemical Analysis

pH was measured in situ using a pH meter, and the temperature using a thermometer. BOD was measured by the Winkler titrimetric method (SNI 06-6989.72-2009). COD was determined by the dichromate reflux titrimetric method (SNI 6989.2:2019).

Data Analysis

Data were analyzed using GraphPad Prism 10 software, and statistical analysis was performed using the one-way analysis of variance (ANOVA) test.

RESULTS AND DISCUSSION

Identification of Bacteria

Based on the identification results visualized on the spatial map in Fig. 5, MALDI-TOF MS identification found diverse bacteria in six zones, including *Acinetobacter iwoffii, Acinetobacter haemolyticus, Enterobacter aerogenes, Proteus mirabilis, Escherichia coli, and Bacillus* sp., and *Pseudomonas* sp. were also found in Zone VI.

Fig. 5: Distribution of organic pollutant-degrading bacteria.

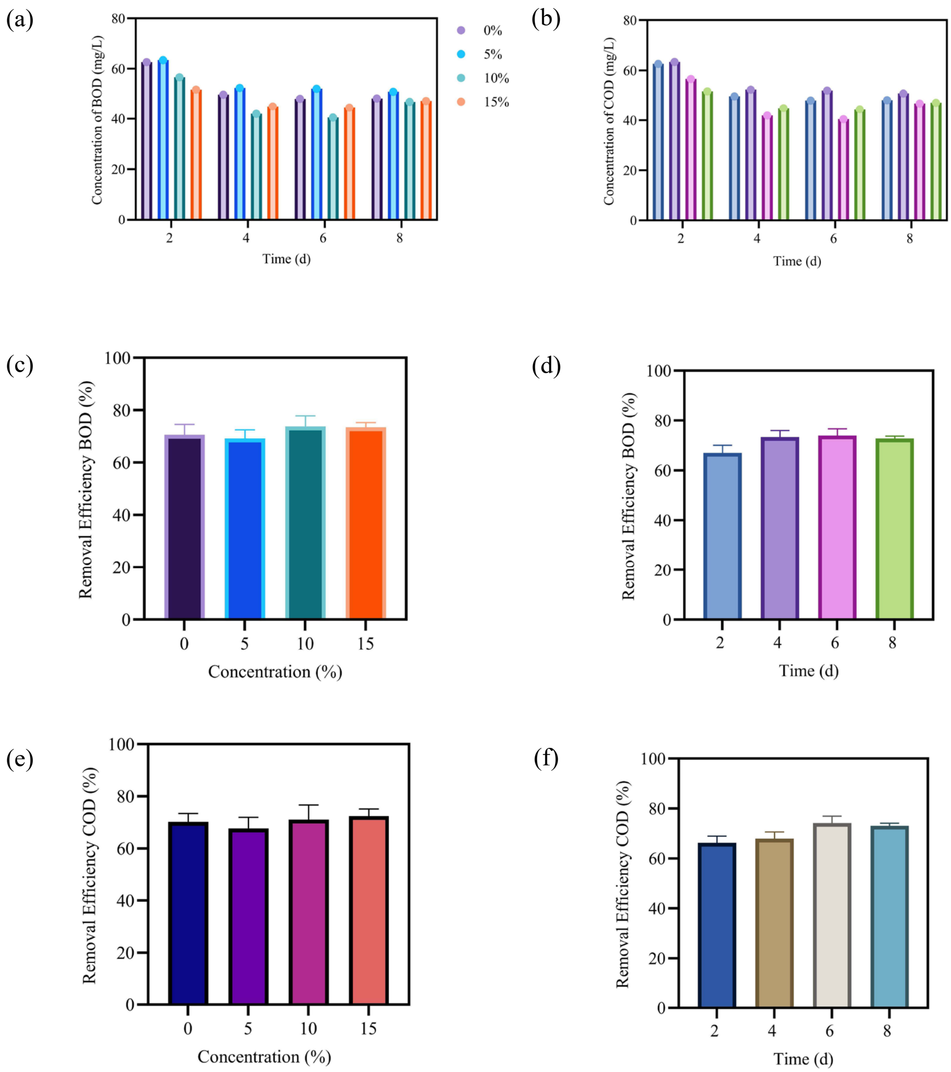

Fig. 6: (a)(b) BOD and COD concentrations, (c)(d)(e) (e) BOD and COD efficiency.

Effectiveness of Bioremediation

pH and temperature remained stable during the experiment (Table 1), providing suitable conditions for microbial activity.

Table 1 shows the results of the pH and temperature measurements over 8 days at 2-day intervals. The pH value was stable in the range of 7.73–7.74 (average 7.7), while the temperature ranged from 27.8 to 28.8°C (average 28.4°C), indicating constant conditions suitable for microbial activity.

Fig. 6(a) shows the BOD and COD concentration trends. The greatest decreases in BOD and COD were observed with 10% inoculum at day 6 from an initial concentration of 177.5 $mg.L^{-1}$ to 40.50 $mg.L^{-1}$. Conversely, the smallest decrease in BOD occurred at a bacterial concentration of 5% on day 2, with a value of 63.40 $mg.L^{-1}$. Fig. 6(b) shows a similar pattern for COD, with the largest decrease in COD occurring at a bacterial concentration of 10% on day 6, namely, from 449.32 $mg.L^{-1}$ to 101.35 $mg.L^{-1}$. Conversely, the smallest decrease in COD, namely 164.31 $mg.L^{-1}$, occurred at a bacterial concentration of 5% on day 2. BOD removal efficiency across inoculum concentrations ranged from 64.73% to 77.18%, and one-way ANOVA showed no significant differences between inoculum concentrations ($p > 0.05$). COD removal efficiency ranged from 63.43% to 77.44%, with no significant differences between the inoculum concentrations ($p > 0.05$). For both BOD and COD, removal efficiencies increased from day 2 to day 6 and decreased slightly by day 8. One-way ANOVA showed that incubation time had a significant effect ($p < 0.05$), with the highest efficiencies observed on day 6.

Discussion

Bacterial Identification

Domestic wastewater obtained from Spermonde Island was subjected to laboratory testing to identify the bacteria present. The results showed several types of bacteria in the wastewater samples. *Escherichia coli* and *Bacillus* sp. were found in zones I and II, *Acinetobacter iwoffii* and *Bacillus* sp. were found in zone II, *Acinetobacter haemolyticus* and *Enterobacter aerogenes* in zone I, *Proteus mirabilis* and *Bacillus* sp. *in* zone III, and *Pseudomonas* sp. and *Bacillus* sp. in zone VI. These bacteria belong to the group of gram-negative bacteria, except *Bacillus sp.,* which is a gram-positive bacterium. In this study, further analysis of the local isolate from zone VI (Fig. 5) showed that the strain was *Pseudomonas aeruginosa*.

Pseudomonas aeruginosa is a bioremediation agent owing to its superior physiological and biochemical capabilities, including its ability to aerobically and anaerobically metabolize various complex organic compounds. This bacterium is also known to have a high tolerance to extreme environmental conditions and rapid adaptability to new habitats, making it a potential candidate for environmental biotechnology applications. In the context of small islands with limited domestic wastewater management systems and a high potential for environmental pollution owing to population density, the use of *Pseudomonas aeruginosa* offers an efficient and sustainable biological solution for significantly reducing BOD and COD levels. *Pseudomonas aeruginosa* is effective in reducing pollutants in domestic wastewater, specifically BOD by 70–85% and COD by 65–80%. *Pseudomonas aeruginosa* possesses enzymes that effectively break down various organic compounds that are responsible for high BOD and COD levels (Naloka et al. 2024). The effectiveness of *Pseudomonas aeruginosa* in wastewater bioremediation is presented in Table 2.

Although *Pseudomonas aeruginosa* has great potential in waste treatment, it should be noted that *Pseudomonas*

Table 2: Wastewater bioremediation by *Pseudomonas aeruginosa* bacteria.

Waste Type	Results	Reference
Petroleum refinery wastewater	83% reduction in COD,	(Aswani et al. 2025)
Alcoholic beverage industry wastewater	COD reduction efficiency of the control group 45% - 49%, (67% - 71%) treatment group	(Huang et al. 2025)
Industrial wastewater	BOD and COD reduction efficiency 82.35%	(Shah et al. 2025)
Industrial waste	COD degradation efficiency 76.3 ± 2.8%	(Yin et al. 2025)
Textile dye waste	Reduction of BOD 70.16% and COD 49.23%	(Chellapandian et al. 2024)
Landfill leachate water	COD and BOD reduction efficiency >70%	(Arliyani et al. 2023)
Distillery wastewater	Reduced COD 61.32% and BOD 53.53%	(Ratna & Kumar 2022)
Industrial effluents	BOD and COD reduction efficiencies were 91.3 ± 2.1%, 97.6 ± 3.3%, and 94.3 ± 4.4%, respectively.	(Al-Ansari et al. 2021)
Factory wastewater	COD removal efficiency of 92% in the BA reactor and 85% without a reactor	(Ruan et al. 2020)
Wastewater automobile service station	COD removal was 94%	(Mallick & Chakraborty 2019)

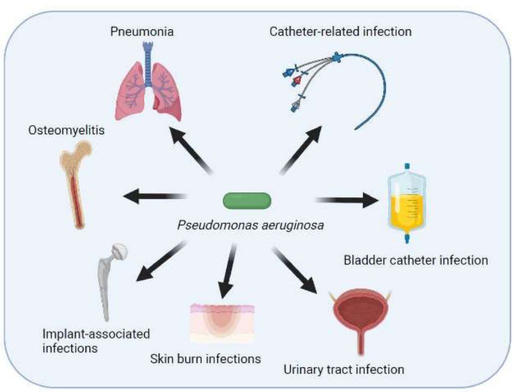

Fig. 7: Schematic representation of the main infections caused by *Pseudomonas aeruginosa*.

aeruginosa is classified as an opportunistic pathogen that can pose health risks, especially to individuals with weak immune systems. Some infections in humans are shown in Fig. 7 (Tuon et al. 2022).

Therefore, it is necessary to implement appropriate risk management or mitigation strategies to minimize the potential negative impacts of *Pseudomonas aeruginosa* in waste treatment. In this study, a closed reactor was used as a mitigation measure to prevent the release of bacteria into the environment. In addition, further mitigation was carried out through the sterilization of final waste to ensure safe microbiological quality and compliance with environmental utilization standards. Sterilization was carried out by applying a chemical disinfection method as the final stage, which is commonly used to eliminate microorganisms in wastewater (Putra et al. 2024).

Bioremediation Effectiveness

pH and Temperature

Environmental factors, such as temperature and pH, are important parameters that influence the success of bioremediation. These two parameters determine the level of metabolic activity of microorganisms and the stability of enzymes involved in pollutant degradation. In this study, these values were within the optimal range for the growth and metabolic activity *of Pseudomonas aeruginosa*. This bacterium can grow well at neutral to slightly alkaline pH and mesophilic temperatures. pH stability indicates that during the degradation process, there were no significant changes that could inhibit enzymatic activity, whereas a constant temperature supported the optimal rate of biological reactions. Thus, the stability of these two parameters indicates that the incubation environment was sufficiently conducive to supporting BOD and COD bioremediation processes by *Pseudomonas aeruginosa* on the small island (Alsukaibi et al. 2023).

In general, mesophilic microorganisms that live at temperatures between 20 and 40°C are the most widely used in the biodegradation process. Temperature plays an important role in influencing the rate of this process. Increasing the temperature to the optimal limit can accelerate microbial activity, whereas excessively high temperatures can inhibit microbial growth and enzymatic activity. Conversely, low temperatures tend to slow down the biodegradation process, although microbial activity can still occur at a slower rate than at higher temperatures. In addition to temperature, the pH of the environment is an important factor that affects the efficiency of biodegradation because it directly impacts the activity and survival of microorganisms (Aswani et al. 2025).

The optimal pH range varies depending on the type of microbe and organic compound being degraded, but generally ranges from pH 6 to 9. pH values outside this range can reduce the efficiency of microbial activity. In the context of bioremediation, pH affects the adsorption of contaminants by microorganisms. High pH (alkaline) levels tend to promote precipitation, whereas low pH can increase the attraction of contaminants to the surface of microbial cells, affecting the interaction between microorganisms and pollutants (Moreno et al. 2024).

Biochemical Oxygen Demand (BOD) Analysis

The initial BOD concentration of 177.5 $mg.L^{-1}$ decreased significantly. Fig. 6(a) shows that in the control (0%), the BOD decreased from 62.60 $mg.L^{-1}$ (day 2) to 48.18 $mg.L^{-1}$ (day 8). This decrease was caused by the activity of indigenous microorganisms naturally present in the wastewater sample, which could degrade organic compounds even without the addition of external bacteria. However, in the treatment with the addition of *Pseudomonas aeruginosa,* the efficiency of organic degradation increased by approximately 5–8% compared to the control. This indicates that the presence of additional inoculum can accelerate the breakdown of complex organic compounds into simpler forms.

The addition of 5% inoculum showed a decrease from 63.40 $mg.L^{-1}$ to 50.84 $mg.L^{-1}$ in the same period. The 10% treatment experienced a decrease from 56.60 $mg.L^{-1}$ (day 2) to a low of 40.50 $mg.L^{-1}$ (day 6) before increasing again to 46.84 $mg.L^{-1}$ (day 8). Meanwhile, the 15% concentration decreased from 51.68 $mg.L^{-1}$ (day 2) to 44.50 $mg.L^{-1}$ (day 6) and then increased to 47.18 $mg.L^{-1}$ (day 8). The increase in the 10% and 15% concentrations on day 8 was influenced by the maximum degradation capacity of bacteria. Each bacterium has a limited capacity to degrade organic matter. Once this capacity is reached, an increase in the number of bacteria is no longer proportional to the increase in degradation effectiveness. This situation is often referred to as the saturation point, where the ratio of available substrate to bacterial population no longer supports an increase in the degradation rate (Altowayti et al. 2022).

In addition, the increase in BOD during this period can be determined by observing the pattern or curve of bacterial growth, which consists of several phases: lag (adaptation), log (exponential growth), stationary, and death phases. On days 2 and 4, the bacteria were in the lag and log phases, where they adapted to the new environment, followed by the log phase, where the bacterial population grew rapidly and enzymatic activity was high, enabling maximum degradation of organic matter, as seen in the significant decrease in BOD, especially at a concentration of 10%, which reached 41.98 $mg.L^{-1}$ on day 4 and 40.50 $mg.L^{-1}$ on day 6. During the incubation period, bacterial activity exponentially accumulated. The number and enzymatic activity *of Pseudomonas aeruginosa* increased with time. Under favorable environmental conditions, bacteria continue to multiply and accelerate the degradation of organic compounds, thereby increasing the efficiency of pollutant reduction, such as BOD.

On days 6–8, the bacteria entered the stationary or death phase, especially at higher concentrations (10% and 15%). In this phase, bacterial growth begins to slow, possibly due to nutrient depletion and the accumulation of toxic metabolites, such as organic acids. In addition, at high bacterial concentrations, competition between bacterial cells for nutrients and dissolved oxygen becomes more intense. Oxygen deficiency in the environment causes the degradation process to be ineffective and can even trigger the activity of other microorganisms, such as anaerobic or facultative bacteria, that produce reductive compounds that actually increase the BOD load. In contrast, during the death phase, dead bacterial cells undergo lysis or rupture, releasing their contents, such as proteins, lipids, and nucleic acids, back into the medium. These compounds are organic and easily degradable, thereby increasing the concentration of dissolved organic matter, as indicated by an increase in BOD (Aswani et al. 2025).

Based on Fig. 6(c), the BOD removal efficiency at various bacterial inoculum concentrations ranged from 64.73 to 77.18%. The highest efficiency was observed at a bacterial concentration of 10%. Fig. 6(d) shows that the efficiency increased from ±64% on day 2 to 70.51-78% on days 4 and 6, and then decreased slightly on day 8 (71 - 73%). The highest efficiency at an incubation time of six days was 77.18%. Although there was a decrease in BOD and an increase in efficiency with variations in bacterial concentration, the results of the one-way ANOVA test showed that bacterial concentration did not have a significant effect ($p > 0.05$). The same study stated that bacterial concentrations ranging from 0.7–1% did not significantly affect BOD reduction. Although BOD decreased in both treatments, the reduction efficiency at a concentration of 0.7% was higher at 80% compared to a concentration of 1%, which only reached 72% (Fathina 2024).

The incubation time had a significant effect on the reduction of BOD in domestic wastewater on small islands ($p < 0.05$). The incubation time of bacteria plays an important role in determining the effectiveness of the organic matter degradation process in waste. The longer the incubation time, the more time bacteria have to increase their metabolic activity, thereby optimizing the degradation process (Safitri et al. 2025). The same study showed that incubation time significantly affected the effectiveness of BOD reduction in hospital wastewater. The results of the study noted that BOD reduction reached 73.86% with a residence or incubation time of 24 h using a zeolite bioreactor bioball with added *Pseudomonas aeruginosa* bacteria in a case study at Prambanan Regional General Hospital (Desica et al. 2020).

Pseudomonas aeruginosa degrades dissolved organic matter in water via aerobic metabolism and enzyme production. *Pseudomonas aeruginosa* uses oxygen to degrade organic compounds under aerobic conditions and involves enzymes that break down complex organic compounds into simpler compounds that can then be used as a source of energy and carbon by microorganisms. *Pseudomonas aeruginosa* produces various enzymes, including lipase, protease, and amylase, which assist in the breakdown of lipids, proteins, and carbohydrates. This process increases the availability of digestible organic substrates, thereby reducing BOD (Grbavcic et al. 2011, Hu et al. 2023).

Chemical Oxygen Demand (COD) Analysis

Based on COD measurements after degradation by *Pseudomonas aeruginosa* in domestic wastewater on a small island, COD decreased with increasing incubation time and bacterial concentration. The initial COD was recorded as 449.32 $mg.L^{-1}$, indicating a high organic load. As shown in Fig. 6(b), the COD of the control (0% additional bacteria) decreased from 146.85 $mg.L^{-1}$ (day 2) to 120.66 $mg.L^{-1}$ (day 8), indicating degradation by indigenous microorganisms. The 5% treatment showed a decrease in COD from 164.31 $mg.L^{-1}$ to 127.10 $mg.L^{-1}$ during the same period, which was greater than that of the control but did not achieve the maximum degradation efficiency. At a 10% concentration, COD decreased significantly from 157.40 $mg.L^{-1}$ (day 2) to 101.35 $mg.L^{-1}$ (day 6), and then increased again to 117.04 $mg.L^{-1}$ on day 8. This indicates that the degradation effectiveness of *Pseudomonas aeruginosa* was optimal until day 6 but subsequently decreased due to substrate limitations or environmental conditions that were no longer supportive. The increase in COD on day 8 was comparable to a concentration of 15% (117.84 $mg.L^{-1}$), indicating that high bacterial concentrations have the potential to trigger population imbalances, nutrient competition, and the accumulation of toxic metabolites.

The decline in COD in wastewater from small islands reflects the growth phases *of Pseudomonas aeruginosa* during biodegradation. On day 2, the bacteria were in the lag phase, transitioning towards the logarithmic phase, so the COD value was still high, although a faster adaptation was observed at a concentration of 15% (137.10 $mg.L^{-1}$). On day 4, the bacteria entered the logarithmic phase, characterized by maximum metabolic activity, as indicated by a significant decrease in COD, particularly at 10% and 15% (lowest at 128.98 $mg.L^{-1}$). On the 6th day, the system reached a stationary phase, marked by a decrease in degradation efficiency owing to substrate limitations and metabolite accumulation. Furthermore, with a longer contact time (day 8), the degradation process began to slow and even tended to stagnate owing to nutrient competition and saturated environmental conditions (Khadijah et al. 2023).

Fig. 6(e) shows the COD removal efficiency at various bacterial inoculum concentrations, with an efficiency range of 63.4– 77.44%. The highest efficiency was achieved at a bacterial concentration of 10%. Fig. 6(f) shows that the efficiency increased from 63.43% on day 2 to a range of 64.79 - 77.44% on days 4 and 6, and then decreased slightly on day 8 to 71-73%. The highest efficiency was achieved after 6 d of incubation. One-way ANOVA showed that bacterial concentration did not have a significant effect ($p > 0.05$). The same study stated that *Pseudomonas aeruginosa* has a high ability to reduce COD by up to 79%, but an increase in microbial population or bacterial concentration does not always correlate directly with the effectiveness of COD reduction. This indicates that the number of bacteria alone is insufficient to determine the success of COD degradation.

Conversely, the results of the one-way ANOVA on COD levels based on incubation time showed significant values ($p < 0.05$). This indicates that incubation time plays an important role in the COD reduction process, and variations in incubation duration can affect the level of organic oxidant degradation in the system. The same study reported that incubation time significantly affected the reduction in COD values(Harahap et al. 2023). Thus, although the bacterial concentration factor can modify the degradation rate, the duration of microbial exposure to the substrate is critical for achieving optimal COD reduction levels. A longer incubation period tended to increase the COD efficiency to a certain point. Thereafter, the increase effect becomes saturated depending on environmental conditions and substrate availability (Yin et al. 2025).

Implementation Implications for Small Island

The characterization of small islands with limited waste treatment facilities, water quality that is highly susceptible to pollution, and seawater intrusion that increases salinity requires the presence of adaptive microorganisms to support bioremediation efforts. *Pseudomonas aeruginosa* is a bacterium with high metabolic flexibility, capable of growing under both aerobic and anaerobic conditions, and is tolerant to variations in nutrient and salinity levels. This ability makes it a potential candidate for domestic waste treatment on small islands, where water quality is easily degraded due to high community activity and limited waste treatment infrastructure. In addition, this bacterium has an enzymatic system that is effective in breaking down complex organic compounds, thereby significantly reducing BOD and COD levels, even under dynamic and challenging environmental conditions. Thus, the use of *Pseudomonas aeruginosa* is ecologically and sustainably relevant, as it is in line with the need for adaptation in island regions vulnerable to changes in environmental quality.

The results of this study indicate that optimizing the waste treatment process can be achieved more effectively through retention time adjustment. In the context of small islands equipped with household-scale communal wastewater treatment plants (WWTPs), these results are practically relevant as they open up the possibility of implementing more efficient, economical, and easily replicable wastewater treatment strategies. The results also confirmed the ability *of Pseudomonas aeruginosa* to adapt to a range of inoculum concentrations. However, an adequate incubation time is required for metabolic activity to reach optimal conditions for reducing pollutant loads. Thus, this study provides an empirical basis for the development of more effective and sustainable domestic wastewater management practices in small island regions, focusing on optimizing the process duration and environmental conditions that support the activity of degrading microbes.

Research Limitations

Although the results of the study show promising potential, this study has several limitations that need to be considered before it can be implemented on a larger scale. First, the use of *Pseudomonas aeruginosa* is associated with simpler health risks, thus requiring strict supervision and control during its application. Second, the research parameters only focused on measuring BOD and COD; therefore, other aspects, such as measuring nitrogen and phosphorus levels, were not examined, meaning that nutritional factors could not be analyzed as variables affecting the effectiveness of bioremediation. These limitations provide a basis for further research with a more comprehensive scope.

CONCLUSIONS

Pseudomonas aeruginosa effectively reduced BOD and COD in domestic wastewater from a small island context. Variations in bacterial concentration did not significantly affect BOD and COD reduction, whereas incubation time had a significant effect, with optimal degradation occurring on day 6. Based on these findings, we recommend that *Pseudomonas aeruginosa-based* bioremediation focus on optimizing incubation time to achieve maximum BOD and COD reduction.

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