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Potential Reuse of Treated Domestic Wastewater Effluent from a Wastewater Treatment Plant (WWTP) for Landscape Watering at PT X

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Abstract

Water is an essential resource for life, and its use in various activities generates domestic wastewater that may potentially pollute the environment, making treatment through a Domestic Wastewater Treatment Plant (WWTP) necessary. This study aimed to identify the characteristics of domestic wastewater at PT X, describe the wastewater treatment process, compare the quality of treated wastewater with the quality standards stipulated in Regulation of the Minister of Environment/Environmental Control Agency of the Republic of Indonesia Number 11 of 2025, Annex I, Point B, and calculate water-use efficiency following the reuse of treated wastewater for watering the landscape. The results showed that domestic wastewater at PT X contained pollutant parameters requiring treatment. The WWTP treatment process, consisting of a grease trap, equalization tank, aerobic Moving Bed Biofilm Reactor (MBBR), clarifier, filtration, biocontrol, and disinfection, effectively reduced the pollutant load, resulting in treated wastewater that met the applicable quality standards. Reusing treated wastewater for watering the landscape resulted in water-use efficiency of 47.6% and wastewater utilization efficiency of 100%, indicating that all generated wastewater was treated and reused. Therefore, the WWTP system at PT X was effective in supporting wastewater management and has the potential to provide an alternative water source for landscape watering application while contributing to water conservation.

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INTRODUCTION

Water is the basis of life, being generally accepted as a fundamental component. This highlights a major issue facing the planet nowadays: guaranteeing the availability of safe and clean water. Several factors determine the water issue: population increases, climate change, and unsustainable water consumption resulting from certain policies (Alazba et al., 2025). Human activities involving water generate domestic wastewater. In addition to humans, plants also require water to sustain their growth and survival. Adequate water availability in terms of quantity, quality, and continuity is essential for plants, as water serves as a fundamental component of metabolic processes. Our pursuit of progress and development often causes us to overlook the environmental impact of our actions, and one such consequence is the excessive generation of domestic wastewater from sources such as kitchens, laundry facilities, and showers (Mohamed et al., 2025). As the population continues to increase, the volume of domestic wastewater generated also increases. Recent population expansion has resulted in a shortage of fresh water supplies needed to support society's basic needs for agricultural, industrial, and urban applications. In some parts of the world, water use has increased more than twice as quickly as population growth (Nason et al., 2026). The importance of exploring alternative non-conventional water resources to support sustainable management and address increasing demands (Hoseinzadeh et al., 2024; Hoseinzadeh et al., 2026). Pollution caused by domestic wastewater can negatively affect the quality of water and soil, ecosystems, and human health. The accumulation of pollutants in water bodies can significantly affect water availability for surrounding communities. According to the Global Risks Report 2025, water scarcity ranks among the top global risks, with severe consequences for ecosystems, economies, and societies(Martín et al., 2026).

Sustainability has become a crucial aspect of technological developments in recent decades, especially as our natural resources deplete at a rapid rate. To achieve a more sustainable state, countries worldwide have been implementing additional policies, regulations, and standards (Basar & Eskicioglu, 2025). As stated by UNICEF, Water and Sanitation Hygiene (WASH) is one of the Sustainable Development Goals through the availability of clean water. Along with global climate change triggered by various negative impacts of human activities, clean water sources are depleting. There was a decrease in wellsprings, furthermore, industrial and domestic waste also polluted large amounts of surface water. This condition significantly threatens the water supply for the next generations. Therefore, using water appropriately and conducting wastewater management is crucial, as stated in Government Regulation of The Republic of Indonesia No. 22 of 2021 involving environmental protection, implicating mandatory wastewater treatment (Setianingsih et al., 2024). In Gresik Regency, East Java, various business activities and residential areas generate domestic wastewater with diverse characteristics, both in terms of the continuously increasing volume and the organic and biological contents that have the potential to pollute the environment. Previous research concluded that the wastewater treatment implemented was able to meet the applicable quality standards, thereby preventing environmental pollution around the activity site (Asmawati et al., 2023). The implementation of a domestic wastewater treatment system and the utilization of treated water for watering the landscape are driven by the commitment of PT X's management to developing a sustainable company. Wastewater treatment plants (WWTPs) play a central role in protecting receiving environments, preserving water resource quality, and promoting sustainable regional development (Baroud et al., 2026).

In addition to demonstrating environmental commitment, the construction and operation of the Wastewater Treatment Plant (WWTP) also aims to comply with Minister of Environment and Forestry Regulation No. P.68 of 2016, which regulates domestic wastewater quality standards. At that time, the regulation required every business and/or activity that generated wastewater to treat it before discharging it into the environment. This provision has since been updated through the Regulation of the Minister of Environment/Head of the

Environmental Control Agency of the Republic of Indonesia No. 11 of 2025 concerning Wastewater Quality Standards and Wastewater Treatment Technology Standards for Domestic Wastewater. The regulation stipulates that wastewater must be treated before being discharged into the environment or reused in accordance with the applicable regulations. Furthermore, Appendix I, Point B of the regulation establishes wastewater quality standards for the utilization of treated wastewater, including its use for watering the landscape, thereby providing a legal framework for the reuse of treated wastewater from the WWTP as an effort to conserve water resources.

Treated wastewater has been widely adopted as a sustainable alternative for enhancing water security in arid and semi-arid regions worldwide. Several nations have established treated wastewater as a reliable and safe water resource for decades. For instance, Israel, Spain, and Australia have successfully implemented treated wastewater for irrigating crops, parks, and urban green spaces (Zhou et al., 2025). Water reuse, the process of treating wastewater for beneficial purposes (e.g. agricultural irrigation), has emerged as a potentially valuable strategy for enhancing water quality, mitigating water scarcity, and offering a promising alternative water supply (Guerrieri et al., 2025).

Domestic wastewater can be treated in a Wastewater Treatment Plant (WWTP) to ensure that its quality complies with the applicable wastewater quality standards before being discharged into or utilized in the environment. The main desirable output of a Wastewater Treatment (WWT) utility is, of course, the treated wastewater (TWW), crucial from an environmental point of view, given that it allows the return of clean water to the environment (Amaral et al., 2023). The potential utilization of treated domestic wastewater from the WWTP for watering the landscape can contribute significantly to maintaining ecological balance and the availability of clean water. Based on the above considerations, this study aims to examine the characteristics and domestic wastewater treatment system at PT X, evaluate the quality of the treated wastewater against the applicable quality standards for its utilization as water for watering the landscape, and analyze its potential utilization in supporting water-use efficiency at PT X.

METHOD

The research method employed a mixed-method approach, integrating quantitative measurements with descriptive qualitative analysis. The quantitative component comprised six-month monitoring data of treated domestic wastewater quality parameters (TSS, pH, BOD, COD, residual chlorine, and fecal coliform) collected from November 2025 to April 2026. The quantitative results were compared against the Indonesian Ministry of Environment Regulation No. 11 of 2025 (Appendix I, Point B) with additional consideration of water utilization efficiency to evaluate the potential for treated wastewater reuse in landscape watering. The qualitative component involved direct field observations of the WWTP operation and semi-structured interviews with site operational personnel to evaluate the existing wastewater treatment processes and landscape watering feasibility. Qualitative data were analyzed using thematic analysis to contextually interpret the system's operational performance and reuse potential at PT X, Gresik Regency.

RESULT AND DISCUSSION

PT X is a company engaged in environmental quality testing services for various environmental quality parameters. The company is located in the Gresik Regency area, East Java. PT X focuses its services on assisting various government agencies and industrial stakeholders, both in East Java and in other regions of Indonesia, in conducting environmental monitoring, evaluation, and management activities. Through its comprehensive services, PT X is expected to contribute to environmental sustainability while supporting environmentally responsible development.

A significant opportunity to enhance urban water sustainability lies in the reuse of treated wastewater as an alternative to potable water for non-potable applications such as landscape irrigation, urban greening, and building-scale water reuse systems. Reusing TWW can reduce freshwater demand, decrease effluent discharges into receiving water bodies, and enhance overall

resource efficiency in line with circular economy principles (Barreiros et al., 2026).

The subject of this study is the potential utilization of treated domestic wastewater from the WWTP for watering the landscape at PT X. In addition to the treatment aspect, this study also focuses on the reuse of treated domestic wastewater as an effort to improve water-use efficiency. The treated wastewater used for watering activities was analyzed to determine its effectiveness in reducing the demand for clean water. The clean water supply at PT X is obtained from the Regional Drinking Water Company (PDAM). The clean water is used for domestic and production activities is approximately 3.67 m^3/day and used for production activities (laboratory operations), domestic activities (toilets and prayer room), and other activities.

The characteristics of domestic wastewater to be treated in the WWTP, as well as the treated wastewater to be utilized for watering plants, are generally assessed based on several key parameters, namely pH, BOD, COD, TSS, fecal coliform, and residual chlorine. These parameters reflect the overall physical, chemical, and biological conditions of the wastewater. Several types of WWTPs are effective in removing up to 90% of major pollutants, such as BOD, COD, TSS, TDS, ammonia, oil, and grease (Firanita et al., 2024, ; Windasari et al., 2025). A Wastewater Treatment Plant (WWTP) is a system designed to treat wastewater containing various pollutant parameters, such as Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), and others. Several water treatment techniques have been developed, including filtration/sedimentation, chemical (e.g., disinfection, chemical oxidation), physicochemical (e.g. adsorption) and biological (e.g. aerobic digestion, anaerobic digestion) (Krstic et al., 2018; Liao et al., 2018; Ejiohuo et al., 2025). The purpose of constructing a WWTP is to treat and manage wastewater to ensure that it is safe for the environment and the health of living organisms before being discharged into water bodies or reused (Miesta & Amalia, 2026).

The characteristics of domestic wastewater at PT X indicate the presence of pollutant parameters, including BOD at 22.66 mg/L, COD at 44.79 mg/L, TSS at 21.28 mg/L, fecal coliform at 170 MPN/100mL, pH of 8.27, and residual chlorine at 0 mg/L. These parameters require treatment before the wastewater can be utilized for watering plants. The Map of Wastewater Management and Utilization at PT X is shown in Fig. 1.

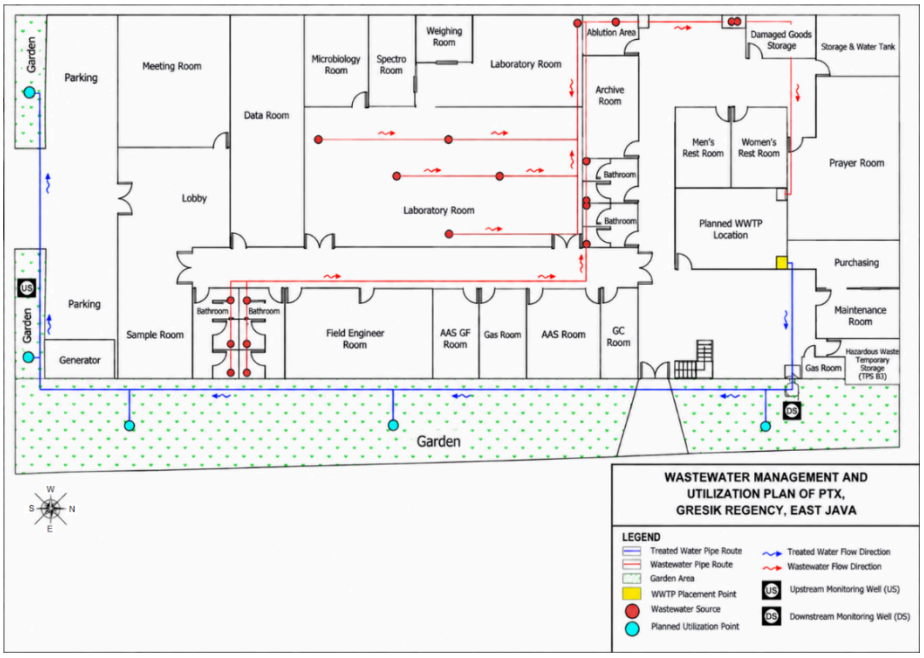

Figure 1. Map of wastewater management and utilization at PT X

Biofilm-based technologies, particularly Moving Bed Biofilm Reactors (MBBRs), have gained attention due to their high biomass concentration, improved pollutant removal,

and operational stability (Zarei et al., 2026). Domestic wastewater treatment technology using biological processes with attached growth has advantages over suspended growth systems, such as low sludge production, resistance to fluctuations in discharge and wastewater characteristics, and increased system efficiency (Huang C et al., 2017; Fauzi M et al., 2023; Fauzi et al., 2025). Examples of this biofilm technology are the fixed-biofilm reactor and moving-bed biofilm reactor systems that have been proven in the removal of organics and nutrients in wastewater (Al Amshawee et al., 2021; Sajad A et al., 2020; Fauzi et al., 2025). The system can be operated under aerobic or anaerobic conditions according to the type of microorganisms developed and the target pollutants to be removed in the wastewater (Al Amshawee et al., 2023; Fauzi et al., 2025).The formation of biofilms on the supporting media consists of several stages, such as adsorption and adhesion of microorganisms to the surface of the supporting media, colonization of microorganisms on the surface of the supporting media, then dividing to form microcolonies and continuing to divide into macrocolonies, and a release process to form new colonies (Tang B et al., 2016; Song Z et al., 2019; Fauzi et al., 2025). So it can be concluded that in the process of biofilm formation, the initial attachment of microorganisms and the development of biofilms are influenced by the adhesion of microorganisms to the supporting media (Mahto KU et al., 2021; Fauzi et al., 2025).

WWTP process flow at PT X (Fig. 2) has a treatment process that begins with wastewater from various sources being conveyed to the grease trap and pit. The grease trap functions to remove oil and grease, while the pit serves as a temporary holding tank as well as an equalization tank to balance the flow rate and characteristics of the wastewater before further treatment. The wastewater is then pumped into an aerobic Moving Bed Biofilm Reactor (MBBR) containing biofilm media, where treatment is carried out with the assistance of blowers to maintain a minimum dissolved oxygen concentration of 2 mg/L. At this stage, the concentrations of COD, BOD, and TSS are reduced. The biological treatment of wastewater harnesses microbial metabolism to remove pollutants (Canals J et al., 2025; (Alihosseini & Mirsalami, 2026). Over the last decades, MBBR has been utilized for the treatment of an extensive variety of wastewater which makes it a compact, flexible and simple technology. As a great advantage, treatment is performed in considerably lower time and less space, which can be interpreted as lower cost compared with traditional treatment methods (Farhami et al., 2025). The moving bed biofilm reactor (MBBR) is another biological treatment procedure that consists of a suspended solid and a biofilm adhered to the carrier. Plastic carriers are used in the wastewater treatment process as a substrate for the growth of biofilms. In a continuously mixed reactor, the reactor uses a significant number of biofilm carriers to enable the development of necessary bacteria (Uddin et al., 2024).

The water then flows into the clarifier, where sludge is separated from the treated water. The clarifier is mainly composed of the reaction tank and the settling tank. The wastewater was mixed in the reaction tank and the mechanical agitation of the stirred paddle improved the kinetic energy of the fluid. Then, the fluid flowed to the settling tank by passing through the overflow wall and the under-through channel. The sludge would settle and separate from the water in the settling tank by inclined tube sedimentation (Xu et al., 2022). Part of the sludge is returned to the aeration tank, while excess sludge is transferred to the drying bed for drying, and the water resulting from the drying process is returned to the pit for further treatment.

The treated water from the clarifier is subsequently collected and conveyed to an intermediate tank, after which it is pumped through filters for further filtration. In the filtration process, membrane technology is utilised, which has attracted a lot of attention because of its reduced energy demand, mild operating conditions, compatibility with other technologies, lesser footprint, and the possibility of optimising the membrane properties to fulfil different needs (Ejiohuo et al., 2025). The water is then conveyed to a storage tank (water tank) for disinfection using chlorine. Following disinfection, the water is conveyed to a fish pond or biocontrol tank, which serves as an indicator of water quality and a location for water sampling.

Once the treated water meets the applicable quality standards, it is utilized for watering plants.

According to the Guidelines of the Directorate General of Spatial Planning, Ministry of Public Works (2007), public green open spaces or landscape have several functions, namely: (1) bio-ecological (physical) functions; (2) socio-economic (productive) functions; (3) urban ecosystem functions, including oxygen production; and (4) aesthetic functions (Marpaung and Rostyaningsih, 2017; Yusuf, 2023).

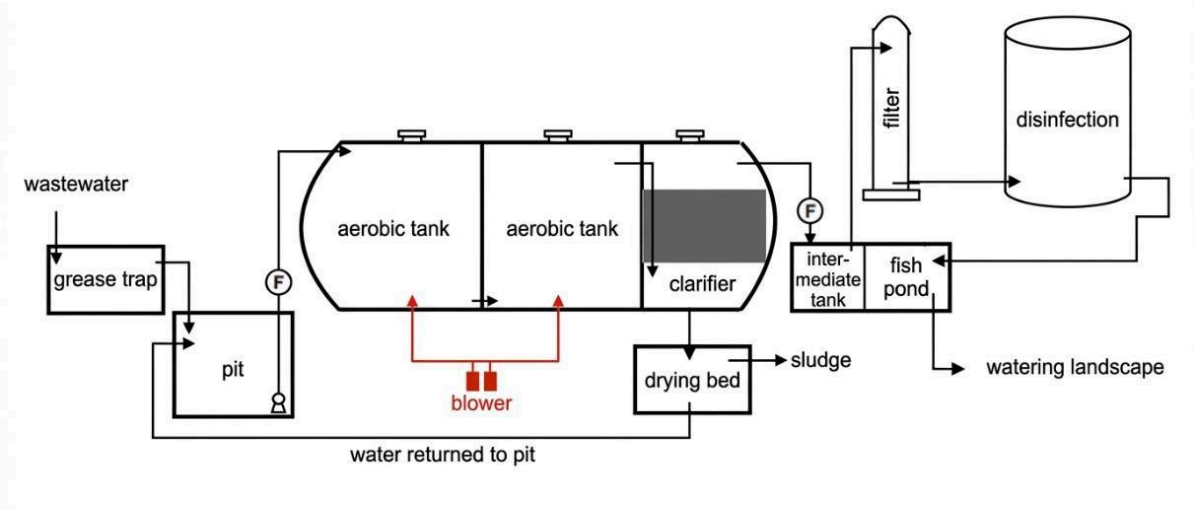

Figure 2. WWTP process flow at PT X

The comparison of treated wastewater quality with the applicable quality standards refers to Regulation of the Minister of Environment/Environmental Control Agency of the Republic of Indonesia Number 11 of 2025, particularly Appendix I, Point B. The graph presents the quality of treated wastewater from the WWTP over a six-month period, based on the following test parameters: TSS, pH, BOD, COD, residual chlorine, and fecal coliform.

At the grease trap, the reduction in TSS is relatively small, at approximately ±10%, because this unit is primarily designed to separate oil and grease (FOG), rather than suspended solids. TSS removal occurs only through simple sedimentation. Subsequently, the pit in the WWTP primarily functions to balance the wastewater flow rate and pollutant load; however, under certain conditions, it can also reduce the TSS concentration. This reduction occurs because relatively calm flow conditions allow suspended particles to settle naturally. If the retention time is sufficiently long and conditions support sedimentation, the process may resemble primary sedimentation, in which TSS removal efficiency can reach 50–70% (Jover et al., 2017; Kato & Kansha, 2024).

According to the Technical Approval Document for Wastewater Quality Standard Compliance of PT X (2024), the removal efficiency of each wastewater treatment unit was evaluated for the relevant wastewater quality parameters. The removal efficiency at each treatment unit indicates the extent to which pollutants are reduced throughout the wastewater treatment process, from the influent to the effluent of each individual treatment unit. In the aerobic unit, the TSS concentration may increase by approximately ±10%. This increase in TSS, or negative removal, may occur due to biomass growth or sludge release. Subsequently, in the clarifier, TSS undergoes a significant reduction of approximately 50%, allowing the treated wastewater to meet the applicable quality standards. The pH value tends to remain stable throughout the WWTP treatment process. Biological treatment is a critical component of wastewater treatment processes, owing to its proven efficacy in eliminating organic pollutants (Baroud et al., 2026).

Biological methods are considered more economical, environmentally friendly, and suitable for reducing BOD and COD from effluents when compared to physico-chemical methods (Vaghamshi et al.,

2025). The BOD of the WW was caused by the presence of unoxidized organic matter (Bogale et al., 2024). The BOD parameter shows a substantial decrease in concentration in the aerobic unit, reaching approximately 90%. An aerobic Moving Bed Biofilm Reactor (MBBR) system can achieve high BOD removal efficiency, approximately 80–90%, particularly under stable operating conditions with sufficient dissolved oxygen (DO), adequate retention time, and active biofilm media. This is attributed to the high concentration of microorganisms attached to the biofilm media, which accelerates the degradation of organic matter in the wastewater. Although WWTPs are equipped with aerobic MBBR systems, conventional treatment processes can achieve overall removal efficiencies exceeding 90% (Lera et al., 2026).

Many researchers have shown excellent COD removal efficiency by biological WWTPs (Hossen et al., 2024). The COD parameter also shows a substantial decrease in concentration in the aerobic unit, reaching approximately 90%. The aerobic biological treatment process in the MBBR unit can significantly reduce COD concentrations through the activity of microorganisms that decompose organic matter into simpler compounds, such as carbon dioxide, water, and biomass. Under optimal operating conditions, including sufficient dissolved oxygen, adequate retention time, and good biofilm growth, COD removal efficiency can reach approximately 80–90%. On the other hand, a majority of works conducted in MBBR fed with synthetic domestic wastewater bearing MPs reported higher COD removals (>90 %) (Eshamuddin et al., 2025).

Theoretically, fecal coliforms should have been almost completely removed during the primary and secondary treatment in sewage treatment plants, especially in the processes of coagulation, sedimentation, and filtration (Ausland et al., 2002; Wang et al., 2023). Nevertheless, some studies (Libutti et al., 2018; Mungray and Patel, 2011) reported that levels of fecal coliforms, which are harmful to public health, were measured in tailwater from sewage treatment plants (Wang et al., 2023). Chlorine disinfection is an extensively used deep treatment method that has been proven to be successful in decolorizing and removing pathogenic microorganisms and viruses in water, including fecal coliforms (Liu et al., 2018; Wang et al., 2023).

Residual chlorine refers to the chlorine remaining in water after the disinfection process in the WWTP. It is generally obtained through the addition of chlorine-based chemicals, such as sodium hypochlorite (NaOCl), using a dosing pump. This process aims to inactivate pathogenic microorganisms that may still be present before the treated water is discharged into the environment or reused.

The residual chlorine concentration must be controlled so that it does not exceed the specified limit, which is approximately 1 mg/L. At this concentration, chlorine remains effective for controlling microorganisms while being sufficiently low to minimize toxic effects on plants, soil, and microorganisms that contribute to soil fertility. Therefore, the dosing pump must be properly regulated to ensure that the chlorine dose is effective for the disinfection process while remaining safe and complying with applicable environmental quality standards. As a potential residual from disinfection processes, free chlorine at concentrations less than one mg/L does not typically pose risk to crop health, but concentrations greater than 5 mg/L can cause severe damage to most plants (USEPA 2012; Chae et al., 2026).

The reduction of fecal coliform in the WWTP occurs gradually through several treatment stages. In the filtration unit, the reduction is relatively low, at approximately 10%, because the mechanism primarily involves the filtration of suspended solids that may carry bacteria, without directly inactivating microorganisms. Meanwhile, in the disinfection tank, fecal coliform reduction can reach approximately 90% or more due to chlorine injection to inactivate pathogens.

Based on laboratory test results for all parameters analyzed (Fig. 3), the quality of the treated wastewater met the required quality standards. Therefore, the treated wastewater is suitable for reuse for non-potable purposes, such as watering landscape. Although the WHO and FAO standards do not specify guidelines exclusively for the long-term use of treated wastewater, they do recommend continuous monitoring, appropriate treatment, and safe agricultural practices to ensure safety over time. The lack of these

safeguards compromises crop safety and the health of end users, highlighting the importance of strengthening treatment processes and ensuring compliance with international standards to enable sustainable reuse (Karef et al., 2025).

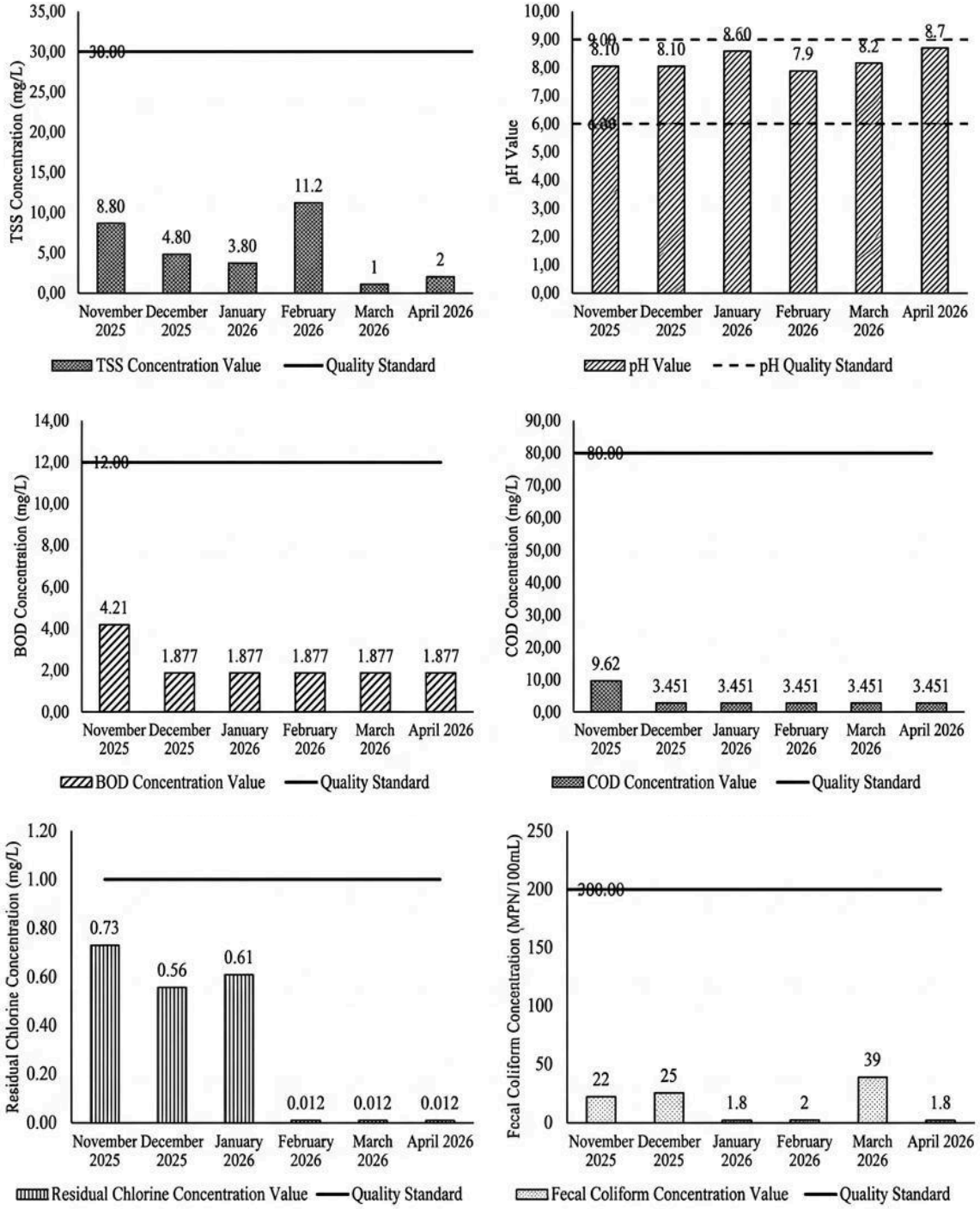

Figure 3. WWTP outlet test results

Water-use efficiency was calculated as follows:

1) Water consumption requirement (A) = 3,67 m^3/day

2)	Wastewater discharge generated for landscape watering (B)	=	3,34 m^3/day
3)	Total water demand if there is no utilization or reuse (C)	=	A+B
		=	3,67 m^3/day + 3,34 m^3/ day 7,01 m^3/ day
4)	Water use efficiency (D)		$\frac{B}{C} \times 100\%$ $\frac{3{,}34\ m^3/day}{7{,}01\ m^3/day} \times 100\%$ 47,6%

Source: Calculation results, 2026
Calculation formula: Widyaningtyas MAS and Asih AS, 2025

This indicates that the utilization of treated wastewater from the WWTP as a water source for watering the landscape has successfully improved clean water-use efficiency.

The wastewater utilization efficiency achieved through the reuse of treated wastewater for land application as water for watering plants is presented as follows:

1)	Discharge from the WWTP used for watering landscape (A)	=	3,34 m^3/day
2)	Wastewater discharge generated (B)	=	3,34 m^3/day
3)	Water use efficiency	=	$\frac{A}{B} \times 100\%$
		=	$\frac{3{,}34\ m^3/day}{3{,}34\ m^3/day} \times 100\%$
		=	100%

Source: Calculation results, 2026
Calculation formula: Putri MC dan Purnomo YS, 2024

Water-use efficiency is an important indicator in sustainable water resource management, particularly in terms of utilizing treated wastewater for landscape watering activities. The use of treated wastewater for soil application as a source for landscape watering is one of the efforts to reduce dependence on freshwater and prevent potential freshwater shortages (Widyaningtyas & Asih, 2025). Treated wastewater is a source of both water and nutrients such as phosphorus, nitrogen, potassium, and many micronutrients (Contreras et al., 2017; Abou Jaoude et al., 2025). Moreover, a substantial portion of the nitrogen and phosphorous available in the treated wastewater can be directly utilized by plants because it is in a more readily available form or mineralized form (Sengupta et al., 2015; Poustie et al., 2020; Abou Jaoude et al., 2025). Though available nutrients in treated wastewater can contribute to crop growth, periodic monitoring of nutrient levels is needed to avoid imbalances in nutrient supply for plants (Pedrero et al., 2010; Orta de Vel´ asquez et al., 2014; Kumar & Yadav, 2025).

Based on the calculation results, the theoretical water demand without wastewater reuse is 7.01 m^3/day, consisting of freshwater consumption of 3.67 m^3/day and a water requirement of 3.34 m^3/day that can be supplied by treated wastewater. Of this amount, 3.34 m^3/day of treated wastewater is reused for watering the landscape in PT X. Accordingly, a percentage of 47.6% is obtained, representing the freshwater substitution rate or the contribution of wastewater reuse to the total theoretical water demand. This means that the reuse of treated wastewater contributes to replacing part of the water demand that would otherwise potentially be supplied by freshwater. In addition, when compared with the volume of treated wastewater generated, namely 3.34 m^3/day, the entire volume is utilized for landscape watering activities, resulting in a wastewater reuse rate of 100%. This condition demonstrates that the

utilization of treated wastewater for landscape watering in PT X can reduce freshwater consumption, increase water resource reuse, and support sustainable water management practices. Therefore, the reuse of treated wastewater for landscape watering is an approach that can be implemented optimally to reduce freshwater demand while improving the efficiency of water resource utilization. Water and wastewater purification and reuse must be greatly increased to safeguard the environment and drastically alleviate water scarcity globally (Jagaba et al., 2024).

The wastewater utilization efficiency reached 100%, generating 3.34 m^3/day of treated water. For the 179 m^2 landscape area, this volume translates to an application rate of 18.67 mm/day. Consequently, the treated wastewater volume is more than sufficient to fully satisfy the daily evapotranspiration demand of the vegetation, confirming the feasibility of this beneficial reuse strategy.

CONCLUSION

Based on the research findings, domestic wastewater at PT X contains several pollutant parameters that require treatment through a WWTP system consisting of equalization, aerobic MBBR, clarification, filtration, biocontrol, and disinfection processes. The treated wastewater meets the applicable quality standards in accordance with Regulation of the Minister of Environment/Environmental Control Agency of the Republic of Indonesia Number 11 of 2025, Appendix I, Point B, and can therefore be utilized as water for watering the landscape. This utilization resulted in a water-use efficiency of 47.6% and a wastewater utilization efficiency of 100%, indicating that domestic wastewater management at PT X supports water-use efficiency and environmental sustainability.

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