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# Communal Wastewater Treatment Plants' Effectiveness, Management, and Quality of Groundwater: A Case Study in Indonesia

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**Abstract:** The Special Region of Yogyakarta is one of the provinces in Indonesia with a large number of communal wastewater treatment plants (CWWTPs). However, less than 40% of CWWTPS in the province are able to be operated well. This study aims to determine the effectiveness of CWWTPs concerning the quality of the surrounding groundwater. The research location was in Mlati, one of three sub-districts with the highest number of CWWTPs and highest population density in the province. Technical data were analyzed in a laboratory, including water quality of CWWTPs and groundwater quality. This study also analyzed non-technical data related to CWWTP management. These data were collected through in-depth interviews with CWWTP managers and users. The data were analyzed systematically, not only quantitatively but qualitatively. The distribution of water quality from CWWTP treatment and groundwater was mapped using inverse distance weighting (IDW). The results show that the CWWTP effluent meets quality standards for pH, temperature, COD, oil and grease, and ammonia. However, some CWWTPs fail to meet the quality standards for the TSS and E. coli parameters. Groundwater has an acidic pH, with ammonia, nitrite, and zinc parameters meeting quality standards, but oil and grease, COD, nitrate, and Pb concentrations exceed quality standards in several wells. This study indicates that the presence of CWWTPs is not correlated with the quality of groundwater due to the inefficiency of the CWWTPs, the unmet coverage area, and the conditions of sanitation facilities at the location.

**Keywords:** CWWTPs; groundwater; inverse distance weighting; water quality

## 1. Introduction

Clean water and sanitation are global environmental issues that the Government of Indonesia has prioritized in its Sustainable Development Goals (SDGs) 2030 agenda, e.g., ensuring the availability and sustainable management of clean water and sanitation for all. The Government aims to achieve 90% access to proper sanitation by 2024, refer to the Presidential Regulation of the Republic of Indonesia Number 18 of 2020 concerning the National Medium-Term Development Plan of 2020–2024 [1]. Effective wastewater management practices are one indicator of access to adequate and sustainable sanitation [2]. The study area is in the Special Region of Yogyakarta where the government developed communal wastewater treatment plants (CWWTPs) to increase the number of house connections. By effectively managing domestic waste, access to proper and sustainable sanitation will be achieved.

According to the Regulation of the Minister of Public Works and Housing No. 4 of 2017 on the Implementation of Domestic Wastewater Management Systems, CWWTP methods are divided into two categories. The first category encompasses CWWTPs, which are managed locally. The second category includes local communal treatment systems. The difference between these two systems is in the number of service connections, which are limited to ten connections (50 people) for a local community system and to four thousand connections (20,000 people) for a centralized CWWTP [3]. CWWTPs are of intermediate size, i.e., these facilities are not economically viable for centralized treatment in large cities but too large for local treatment in settlements in densely populated areas. CWWTPs are the focus of this study.

A communal wastewater treatment plant (CWWTP) is a water treatment system used for domestic wastewater treatment. CWWTPs communally were applied by household groups serving 10–100 households or even more. Effluent from installation processing can be channeled to infiltration wells or directly discharged into a body of water, for instance, a river, lake, etc. CWWTP components consist of a wastewater treatment unit, piping networks (control tubs and treatment pits), and household connections. The wastewater treatment unit is simpler than the sewage treatment on a larger scale. Most communal WWTPs focus on primary and secondary treatment to remove particulate and organic matter. However, CWWTPs are mostly not equipped with disinfection and sludge-treatment units [4,5].

The Special Region of Yogyakarta is one of Indonesia's provinces with a high concentration of CWWTPs. In the city of Yogyakarta alone, there are 87 CWWTP units still operating below the design capacity [6]. Since the late 1990s, referred to as the neighborhood system at the time, CWWTPs have been used in Yogyakarta. Later, CWWTP pilot plants were constructed in areas surrounding the city, namely in Wirogunan, Brontokusuman, and Purwokinanti [7]. However, the development of these CWWTPs was eventually stopped for political reasons and then continued in accordance with the Government's Community Based Sanitation Development Policy [4,5,8] and with support from non-governmental organizations working in the sanitation sector, such as LPPT-DEWATS and Dian Desa-Pusteklim [9]. Although these early CWWTP designs did not meet the applicable quality standards, they introduced wastewater management issues to the public.

Recently, CWWTPs have faced new challenges as stricter wastewater treatment quality standards have been implemented. One of these challenges is that a CWWTP is now considered a source of pollution, both for surface and groundwater [10]. Technically, this cannot be separated from processing methods, the majority of which continue to rely on previous technology using Anaerobic Baffled Reactor (ABR) [11–13]. Not only must that be studied, but things outside of technology still need to be researched, especially non-technical aspects such as social dimensions, economic support, and institutional elements.

Access to adequate sanitation is inextricably linked to access to clean water and drinking water [14]. Protected wells (35%) are the most frequently used source of drinking water in the Special Region of Yogyakarta, followed by bottled water (25%) and drilled/pumped wells (15%) [15]. An analysis of groundwater quality in the study area was published in 2020 [13]. Chemical parameters show that nitrate concentrations in groundwater were 3721–5582 mg/L in 2016 and exceed the quality standard of Regulation of the Minister of Health of the Republic of Indonesia Number 492/MENKES/PER/IV/2010, that is, more than 10 mg/L at six sampling points. At almost all sampling points, the value for the microbiological parameter, specifically E. coli, as well as the total coliform parameter, exceeds the standard of Regulation of the Minister of Health of the Republic of Indonesia Number 492/MENKES/PER/IV/2010 that pathogen bacteria must not be detectable in any 100 mL sample. This may be due to contamination from domestic waste, both direct disposal and seepage into wells from septic tanks located near water sources [16]. The findings indicated that the local sewer pipe and septic tank system is not functioning optimally, so seepage and infiltration of pollutant may occur to the nearest clean water source, such as groundwater. It is also possible that this occur in larger domestic wastewater treatment systems (CWWTPs).

One of the consequences of groundwater pollution by pathogenic bacteria is water-borne diseases such as diarrhea, typhoid, and dysentery [17,18]. The number of people with diarrheal disease in the Special Region of Yogyakarta reached 10,276 in 2020 [15]. According to the Department of Environment and Forestry of the Special Region of Yogyakarta in 2021, diarrhea is the second most common disease, after hypertension [10].

Based on the Environmental Council of Yogyakarta in 2020, community sanitation systems can influence the microorganism contamination of the residents' groundwater. Although prior studies suggest a connection between groundwater quality and CWWTP systems, only limited research has been conducted in the Special Region of Yogyakarta. Importantly, groundwater quality studies and the evaluation of CWWTPs are generally conducted independently, with no studies combining the two. In this study, the performances of CWWTPs and their effect on the groundwater quality of residents' well water are evaluated. The observations summarized herein contribute novel insights into the effect of CWWTP on groundwater quality in this part of Indonesia.

## 2. Materials and Methods

### *2.1. Research Location*

The research location was selected based on data obtained from the Department of Environment and Forestry of the Special Region of Yogyakarta, specifically about the existence and status of CWWTPs in Sleman Regency and the Ngaglik, Depok, and Mlati sub-districts (Figure 1). These sub-districts are areas with the most CWWTP–house connections. However, the study focused only on the Mlati sub-districts due to the COVID-19 situation. Six out of eight CWWTPs were eligible for sampling purposes (CWWTP3 to CWTTP8).

Groundwater quality was determined via monitoring wells with locations based on secondary data analyses of the Regional Environmental Management Performance Information Document (DIKPLHD) of the Sleman Regency in the Government Special Region of Yogyakarta and the Department of Environment and Forestry (DLHK) of the Special Region of Yogyakarta. The monitoring wells were initially selected using the random sampling method; then they were evaluated and changed for purposive sampling and clustering to obtain statistically representative results. The groundwater quality was tested with water from the monitoring wells, which were located within 500 m of a CWWTP and were spread out inside the grid. In total, twenty monitoring wells (W1 to W20) around six CWWTPs were sampled and analyzed.

### *2.2. CWWTP Effectiveness Data Sampling and Analysis*

The water influent and effluent of CWWTPs were taken using the Indonesian National Standard 6989.59 of 2008. All the samples, both sewage and groundwater were taken once. The standard dictates that for the purpose of evaluating the efficiency of the wastewater treatment plant (WWTP), samples were taken at the location before and after the WWTP by taking into account the retention time. The sampling location at the inlet is carried out at the point in the high-tense flow so that good mixing occurs, namely at the point where the waste flows at the end of the production process to the WWTP. If sampling is not possible at the location, then another location can be determined that can represent the characteristics of the wastewater. The sampling location at the outlet is carried out at the location after the WWTP or the point where the wastewater flows before entering the receiving water body (river). The wastewater quality parameters were in accordance with the Ministry of Environment and Forestry of the Republic of Indonesia No. P.68/Menlhk-Setjen/2016 and consisted of pH, Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), oil and grease, ammonia ($NH_3$-N), and total coliform.

Meanwhile, the groundwater was sampled according to Section 58 of the Indonesian National Standard 6989.59 of 2008. The parameters included pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), ammonia, total coliform, and E. coli. The temperature and pH were measured directly in the field with a multimeter. Both CWWTPs and groundwater samples were analyzed in the Environmental Quality Laboratory, Faculty of Civil Engineering and Planning, Islamic University of Indonesia accredited by National Committee of Accreditation of Indonesia. A summary of the analysis methods, specification of equipment, the Limit of Detection (LOD), and other parameters are displayed in Table 1.

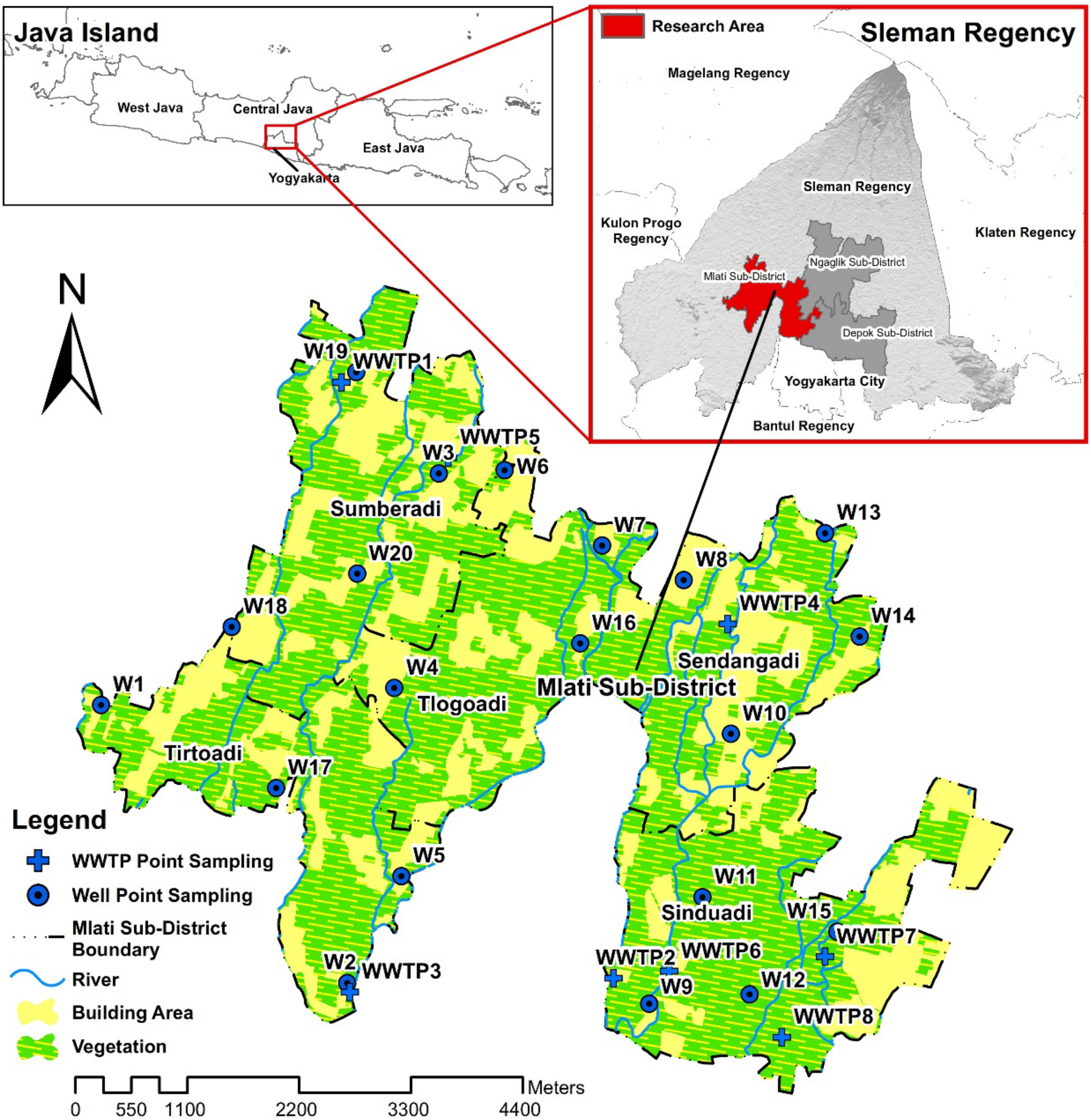



**Figure 1.** Study area and sampling location.

**Table 1.** Standard method of water parameters.

| Parameters | Indonesian Standard Quality | Methods | Equipment, Standard, and Limit of Detection (LOD) |
|---|---|---|---|
| BOD | SNI 6989.72:2009 | Titrimetric | Incubator ET 6265 Lovibond (Tintometer GmbH, Dortmund, Germany); *Glucose-Glutamic Acid* (GGA) |
| COD | SNI 6989.2:2009 | Spectrophotometry | Thermo Reactor ECO 25; Velp Scientifica Sri 505445 (Usmate Velate, Monza and Brianza, Italy); Spectrophotometer UV Vis 1700 (Shimadzu, Kyoto, Japan); standard Sigma Aldrich 500 mg/L; LOD 9.71 mg/L |
| Ammonia ($NH_3$) | SNI 06-6989.30-2005 | Spectrophotometry | LAF Biobase (Shandong, China); Spectrophotometer UV Vis 1700 (Shimadzu, Kyoto, Japan); LOD 0.02 mg/L |
| TSS-TDS | SNI 06-6989.3-2004 | Gravimetric | Oven Memmert UN 110 B420.2432 (Büchenbach, Germany); CRM TSS 100mg/L Sigma Aldrich; TDS 1000 mg/L; LRAC 3286 Sigma Aldrich |
| | SNI 06-6989.10-2004 | Gravimetric | |
| Nitrite & nitrate | SNI 06-6989.9-2004 | Spectrophotometry | Spectrophotometer UV Vis 1700 (Shimadzu, Kyoto, Japan); LOD nitrite 0.002 mg/L, nitrate 0.2 mg/L |
| Pb | SNI 2354.5:2011 | Atomic absorption spectrometry | AAS GBC Avanta (Perai, Malaysia); ICP Multi Element Standard Solution IV Merck 1.11355.0100 (New Jersey, United States); LOD 0.03 mg/L |
| Cu | SNI 6989.6:2009 | Atomic absorption spectrometry | AAS GBC Avanta (Perai, Malaysia); ICP Multi Element Standard Solution IV Merck 1.11355.0100 (New Jersey, United States); LOD 0.01 mg/L |
| Zn | SNI 06-6989.7-2004 | Atomic absorption spectrometry | ICP Multi Element Standard Solution IV Merck 1.11355.0100 (New Jersey, United States); LOD 0.02 mg/L |
| Total coliform and *E. coli* | SNI 2897:2008 | Total Plate Count | Incubator IN 75 Memmert D320.0208 (Büchenbach, Germany); CRM *E.coli* Merck VM 919254 |

### 2.3. CWWTP Management Analysis

CWWTP management aspects involve non-technical data regarding economic, social, and cultural factors. These aspects were investigated with in-depth interviews supported by questionnaires and observations with managers of the CWWTPs and its users as participants. The Ethical Approval (EA) to take the data was established by The Ethics Committee of the Faculty of Medicine, Islamic University of Indonesia, Number 9/Ka.Kom.Et/70/KE/V/2022. Furthermore, CWWTPs' operational and maintenance data, such as the availability of Standard Operational Procedures (SOPs), CWWTP problems, community participation, and monitoring of effluent, were collected from CWWTP managers. While service data such as sanitation conditions, socialization of existing CWWTPs, willingness to make monthly payments, participation in observing the CWWTP's performance, and CWWTP organization were obtained from participating households (five households for each CWWTP). For groundwater analysis, the distance (meters) of the septic tank from the monitoring wells, the depth, the covering of wells, and the existing conditions around the monitoring wells were also investigated. The results were then presented in a graph and analyzed descriptively.

### 2.4. Groundwater Quality Data Analysis

Both influent and effluent of CWWTP water quality was compared to the standard water quality of the Ministry of Environment and Forestry of the Republic of Indonesia No. P.68/MenLHK-Setjen/2016. On the other hand, groundwater quality testing is used to assess groundwater conditions. It can provide critical information about whether pollutant compounds in groundwater exceed the quality standard of the Ministry of Health of the Republic of Indonesia Number 492/MENKES/PER/IV/2010 regarding drinking water requirements, Number 32 of the Year 2017 for the domestic hygiene sanitation, and Ministry of Environment and Forestry No. PP 22/2021 about the implementation of environmental protection and management. Box plots for each parameter visualize CWWTPs' water and groundwater quality data. Moreover, a modified Inverse Distance Weighting (IDW) method [19–21] was used to describe the distribution pattern of groundwater quality parameters at locations near the CWWTPs as well as outside the CWWTPs' coverage area.

The coverage area was measured by grid-box with radius 500 m × 500 m. The raw and basic map was obtained from Ina-Geoportal [22] with a scale of 1:25,000 and was processed further using ArcGIS 10.3.1 for Desktop [23].

## 3. Results

### 3.1. CWWTP Effectiveness

The effectiveness of the treatment process at the CWWTPs was evaluated against the applicability of the Minister of Environment and Forestry Regulation number 68 of 2016 on Domestic Wastewater Quality Standards [24]. More specifically, treated wastewater must meet seven parameters, i.e., BOD, COD, TSS, oil and total grease, temperature, and total coliform. Except for detergent, but including pH, these parameters were analyzed at the inlet and outlet of six CWWTPs (CWWTP2 through WWTP7; Figure 1). According to the results of interviews, there are 625 households connected to these six CWWTPs in the Mlati sub-district. That number of connections remains below the maximum design capacity of the respective CWWTPs. Meanwhile, the Central Bureau of Statistics of Sleman Regency estimates that the Mlati sub-district had 31,783 households in 2020, implying that the proportion of households served or connected to the CWWTPs is less than 2%. This result is similar to previous findings that indicate that many CWWTPs operate well below capacity and that domestic waste is not being processed optimally [25].

Domestic wastewater not connected to the CWWTPs can pollute water resources if it is not treated before being discharged into the environment or water bodies. Because domestic waste in the Special Region of Yogyakarta is still not being managed optimally through CWWTPs, the rivers in the Special Region of Yogyakarta remain polluted. The pollution index in the Winongo, Oyo, Bulus, and Kuning rivers is light to moderate, while the Code River is polluted, and the rivers of Gadjah Wong, Bedog, Conteng, Belik, and Tambak Bayan are heavily polluted [10].

The acceptable domestic wastewater pH standard ranges from 6 to 9. As illustrated in Figure 2a, the pH values of the inlet and outlet at the six CWWTPs met the quality standard. In CWWTP2 to CWWTP4, the pH values at the outlet are lower (7.19; 6.81; 6.75, respectively) than at the inlet (7.81; 7.2; 7.1, respectively), whereas it was higher (6.75; 6.67; 7.04) than the inlet concentrations (6.52; 6.59; 6.5) at the other three locations (WWTP5 to WWTP7). The water temperature at the inlet and outlet was within the quality standards specified. However, the wastewater temperature at the inlet and outlet differed, indicating that the wastewater temperature changed during the treatment process at the CWWTPs.

The results of the TSS analysis of wastewater at the inlets and outlets (Figure 2c) exceed the quality standard for all CWWTPs. Because the concentration of TSS at all sample points tends to cluster on the right side of the distribution, and the frequency of TSS concentration is higher than the average, the distribution of TSS data at the inlet tends to skew to the left (negative skewness). In general, the influent temperature tended to be higher (28.55 on average) than the effluent (27.98 on average). The applicable TSS standard for domestic wastewater is 75 mg/L.

The BOD parameter is critical because it indicates the oxygen required to degrade organic matter contained in the domestic wastewater biochemically. The concentration of BOD at the CWWTPs' inlet exceeded the quality standard, which is 30 mg/L, at all points (Figure 2d). CWWTP4, CWWTP5, and CWTTP6 had the same BOD concentration with a value of 200 mg/L. It was the highest concentration compared to the other three CWWTPs. CWWTP2 had the lowest BOD concentration with a value of 100 mg/L. The outlet concentration of BOD at CWWTP2 (38 mg/L) and CWWTP4 (32 mg/L) did not meet the quality standard after treatment, whereas the water quality standard was met at CWWTP 3, CWWTP5, and CWWTP7 (range: 20–30 mg/L).

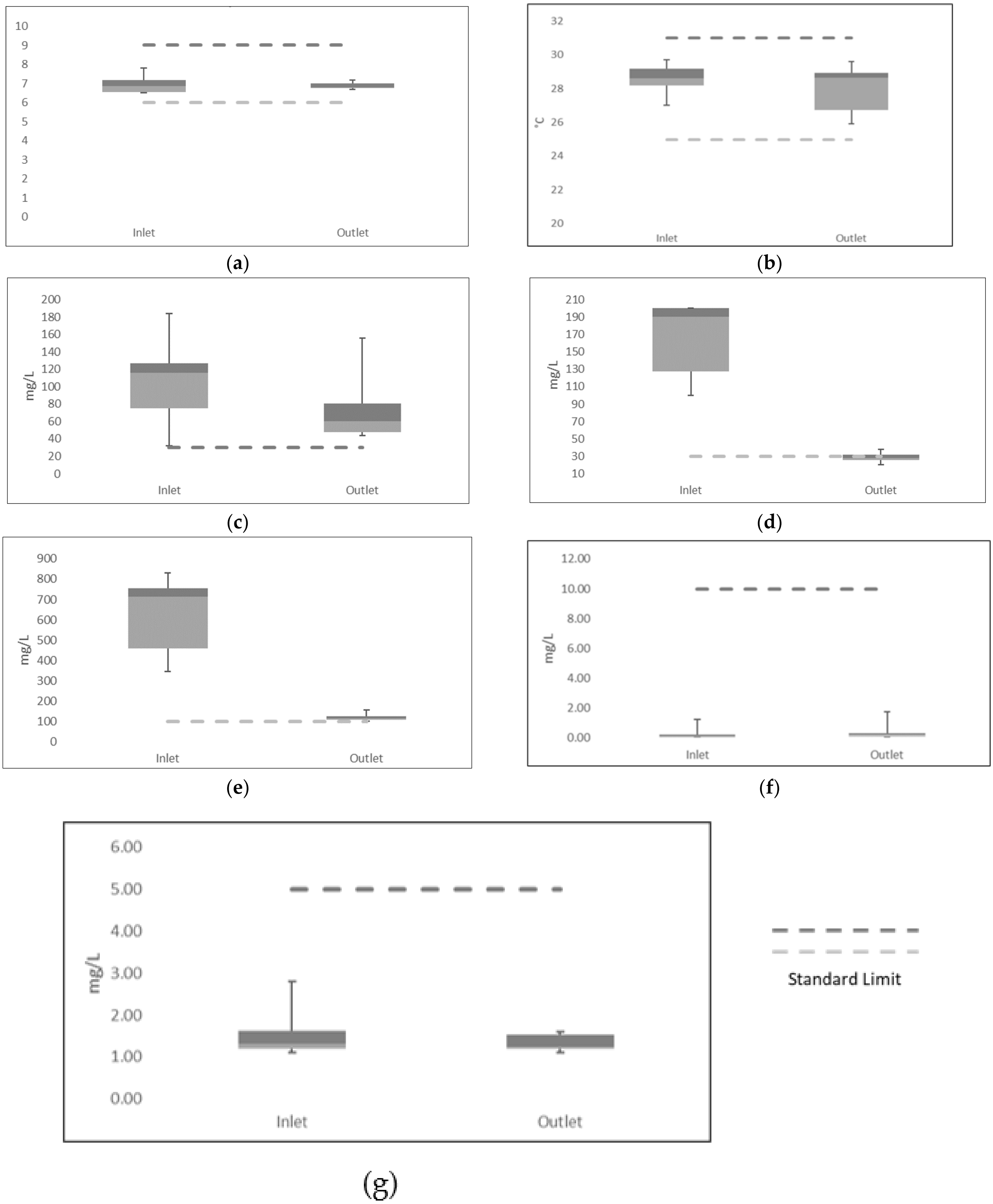
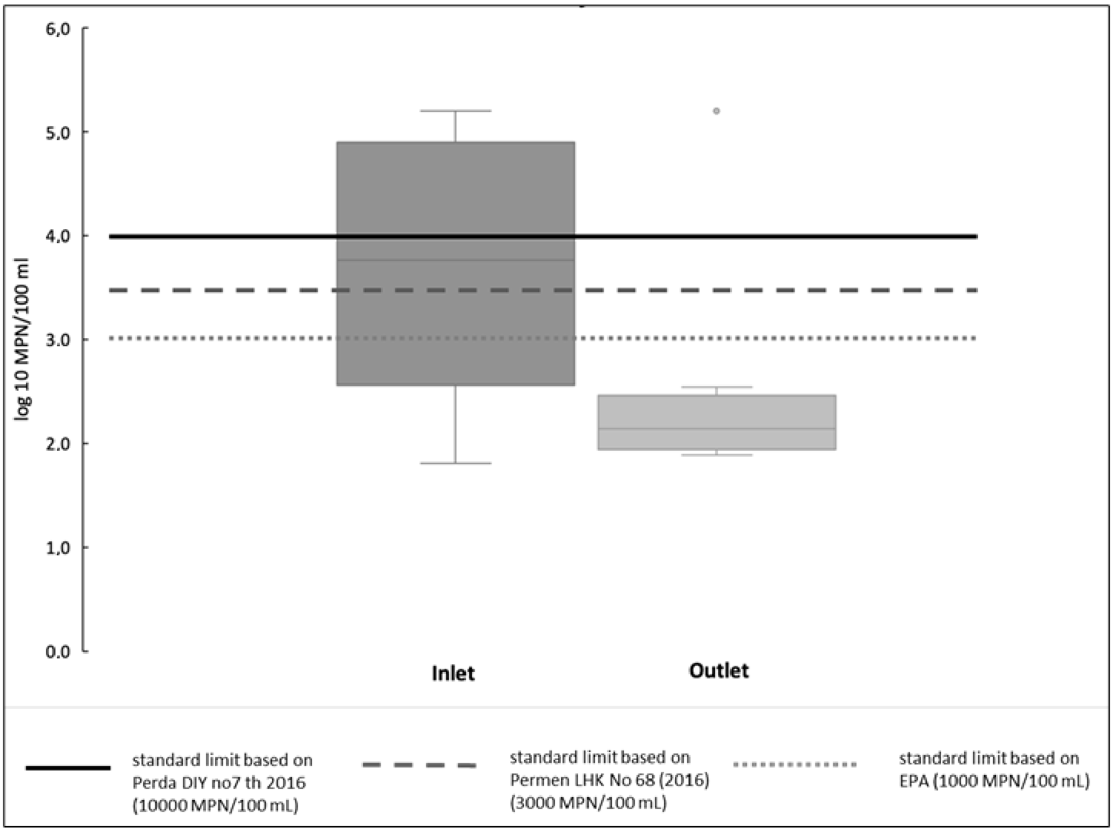



**Figure 2.** *Cont*.




(**h**)

**Figure 2.** Comparison of (**a**) pH, (**b**) temperature, (**c**) TSS, (**d**) BOD, (**e**) COD, (**f**) ammonia, (**g**) oil and grease, (**h**) the average of total coliform from six CWWTPs at the inlet and outlet.

The COD parameter is critical in domestic wastewater analysis because it indicates the oxygen required to degrade the organic matter contained in domestic wastewater chemically. The highest COD concentration (Figure 2e) is at CWWTP5 (830 mg/L), and the lowest is at CWWTP2 (345 mg/L). The COD outlet concentrations ranged from 101 to 156 mg/L, indicating that domestic wastewater treatment at the CWWTPs is not effective.

Figure 2f shows the ammonia concentration at the CWWTPs' inlet and outlet. At the CWWTP6 sample point, the highest ammonia concentration was 1.26 mg/L, while the lowest concentration, i.e., 0.06 mg/L (LOD was 0.02 mg/L) was the same for CWWTP3, CWWTP4, and CWWTP7. Following treatment, the average ammonia concentration at the outlet increased at all locations (up to 1.77 mg/L at CWWTP6) except for CWWTP5, which decreased to 0.06 mg/L.

Figure 2g illustrates the oil and total grease concentrations at the CWWTPs' inlets and outlets. The standard for oil and total grease in domestic wastewater is 5 mg/L. This standard is met for all inlet and outlet. The CWWTP3 sample point has the highest concentration of oil and total grease at 2.8 mg/L, while the CWWTP4 sample point has the lowest concentration at 1.1 mg/L.

Following treatment at the CWWTPs, the concentration of oil and total grease at the outlets increased at two points, CWWTP2 and CWWTP4, but remained below the quality standard. At another point, the oil and total grease concentrations decreased. The distribution of oil and total grease concentrations at the outlet is identical to that at the inlet, which tends to skew to the right (positive skewness). This is evident from the higher frequency of data on oil and total grease concentrations, which are below the average. At the outlet, the highest concentration of oil and total grease is 1.6 mg/L, while the lowest concentration is 1.1 mg/L.

According to EPA regulations and the World Health Organization [26], the effluent standard for discharge into the receiving water body for fecal coliform bacteria is 1000 per 100 mL, which is also considered safe for wastewater irrigation use. In Indonesia, the standard of Minister of Environment and Forestry Regulation No. 68/2016 for wastewater is 3000 MPN/100 mL, whereas the standard for wastewater is 10,000 MPN/100 mL in the Special Region of Yogyakarta's Regulation No. 7 of 201. The Total Coliform results at the CWWTPs' inlets and outlets are summarized in Figure 2h.

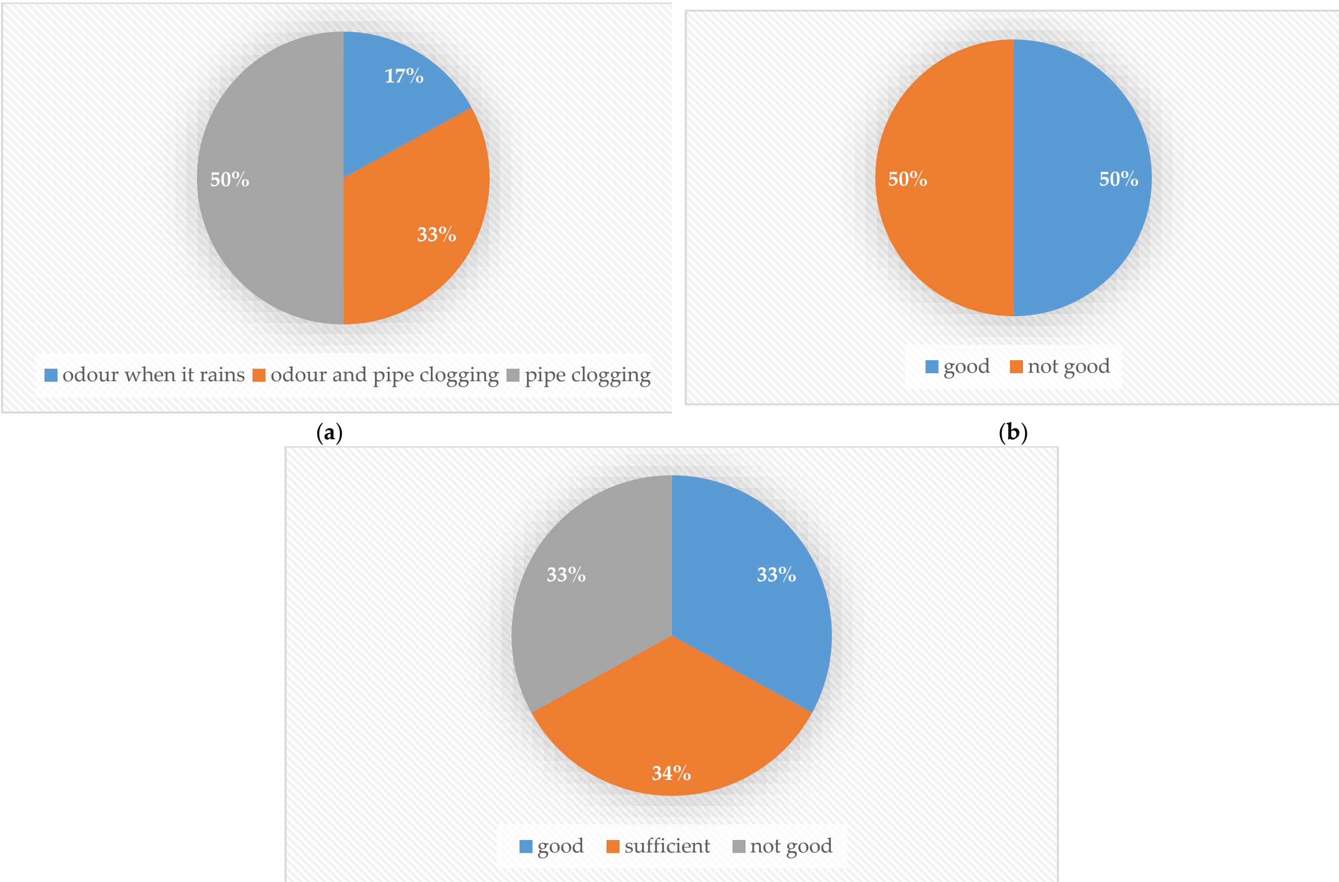
The analysis revealed that the total coliform concentration at CWWTP2, CWWTP6, and CWWTP7 exceeded the standard while at CWWTP3, CWWTP4, and CWWTP5 it met all of the standards. However, all outlets, except at CWWTP3 (160,000 MPN/100 mL), met the Indonesian standard. This demonstrates that five out of six CWWTPs were effective at removing total coliform bacteria contamination. According to survey data, CWWTP3 has issues, specifically odor and clogging. Odor is an indicator of an excess bacterial population [27,28]. When compared to the total coliform concentration at the CWWTP3 inlet, the number was greater. There was also a clogging issue on another CWWTP, but there is no odor issue. However, if this clogging is left, it might cause odors in the future.

### *3.2. CWWTP Management*

#### 3.2.1. In-Depth Interview of CWWTP Managers in the Mlati Sub-District

Interviews with managers and customers of CWWTPs elicited information about the treatment facility management. The total number of households using all CWWTPs sampled in the Mlati sub-district, namely CWWTP2 through CWWTP7, remains below the CWWTP's maximum capacity. Five of six CWWTPs were built by government proposal under the Urban Sanitation and Rural Infrastructure (USRI) program, while the other was built by community and sub-district proposal under the Sanimas (community-based sanitation) program. The land status of the CWWTPs is village treasury land, except CWWTP3, which belongs to a private landowner. The most frequent problem in CWWTP operation is clogging, as noted by 50% of all managers interviewed (Figure 3a.). Furthermore, 17% of managers stated that the CWWTP smells when it rains, and 33% indicated that it smells and is clogged. The presence of garbage in the CWWTP piping network is the leading cause of clogging. In terms of technical problems, such as leaking pipe, clogging, and so on, up to five CWWTPs (83.3%) have never encountered them, while only WWTP3 has experienced them.

Figure 3b,c illustrate citizen participation in CWWTPs operations and payment of CWWTPs fees. In Indonesia, citizens are expected to contribute in various ways to the operation of communal infrastructure, including CWWTPs [29–31]. According to the managers interviewed, citizen participation in the operation of the surveyed CWWTPs is equally good and bad, meaning that only 50% of all citizens fulfill their obligations to the CWWTPs. Except for CWWTP7, all CWWTPs received their maintenance and operational funding entirely from private sources. According to the manager of CWWTP7, the operational funding process is supported by community contributions. Subscription fees for the other plants are IDR 5,000 (USD 0.35) for CWWTP2, 3, 5, and 6, and IDR 10,000 (USD 0.70) for CWWTP4. The collected subscription fees are significantly lower than the monthly cost of CWWTPs, which ranges between IDR 50,000 (USD 3.5) and IDR 1,400,000 (USD 100). According to the managers interviewed, citizen participation in paying subscription fees was rated at the same levels (33.3%) as good, moderate, and bad. This means that about 1/3 of the citizens contribute nothing ('not good') to run the treatment plant. Only 33.3% showed a 'good' payment attitude. The remainder contributed, but just enough to meet the minimum requirements.




(**a**) (**b**) (**c**)

**Figure 3.** Results of survey of CWWTPs managers on (**a**) frequent problems in plant operations related to clogging and odors; (**b**) rating of the citizens' engagement with the CWWTPs; and (**c**) reliability of CWWTP subscription fee payments by the citizens.

### 3.2.2. In-Depth-Interview of CWWTP Users in the Mlati Sub-District

A total of 32 CWWTP users in the Mlati sub-district responded to our survey; with five respondents each from CWWTP2, 3, 5, and 7 and six respondents each from CWWTP4 and 6. In terms of payment for CWWTP subscription, 84% of respondents pay monthly, while 16% do not pay because in their opinion the CWWTP use is free. Figure 4a depicts the amount of fees paid by CWWTP users. Forty-eight percent of respondents made contributions ranging between IDR 1000 and IDR 5000 (maximum USD 0.4), while the remaining 52% contributed between IDR 5000 and IDR 10,000 (maximum USD 0.7). This is in accordance with information from the CWWTP manager, who states that the subscription fee is IDR 5000 for the first year, and IDR 10,000 for the subsequent years.

Regarding subscription fees, 94% of respondents agree that all users should pay the same fee, while 6% agree that subscription fees should be determined by the users' economic status. Figure 4b suggests that 69% of the respondents perceive the CWWTP subscription fees as adequate, while only 6% would like to see the cost reduced. About 25% are willing to pay more towards the CWWTP operation. In terms of the CWWTP performance, as many as 63% of respondents said they were satisfied ('good'), 19% were very satisfied ('very good'), and 19% had some reservations ('quite good').

As displayed in Figure 4c, a total of 37.5% of respondents stated that they were very satisfied with the CWWTP service. In addition, around 37.5% of respondents said they were satisfied, and the remaining 25% said they were quite satisfied with the CWWTP service. In Figure 4d, about 9% stated that there were complaints regarding CWTTP performance, i.e., bad smells because the residents' houses are not far from the CWWTPs. However, 91% stated that there were no issues.

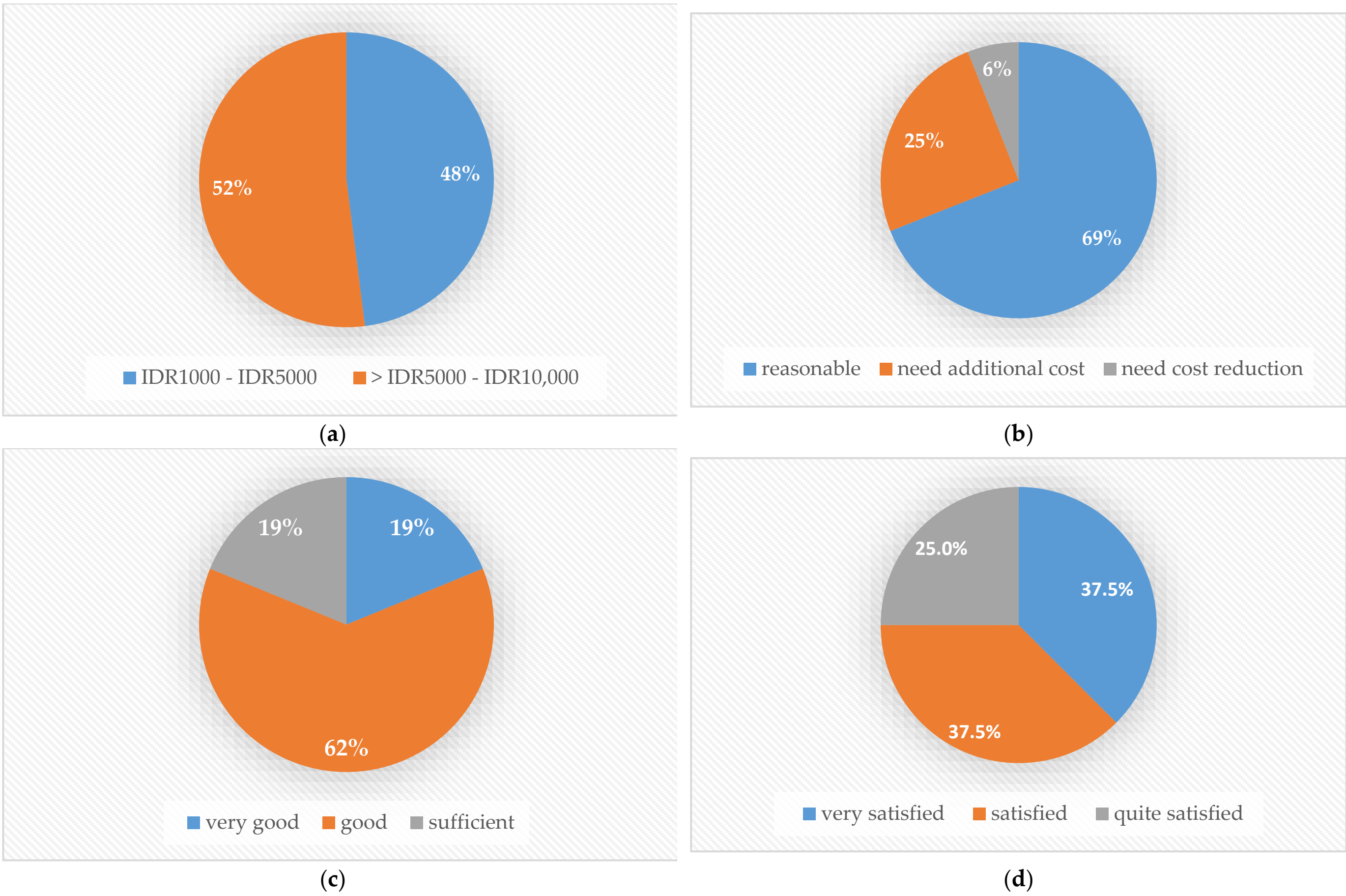


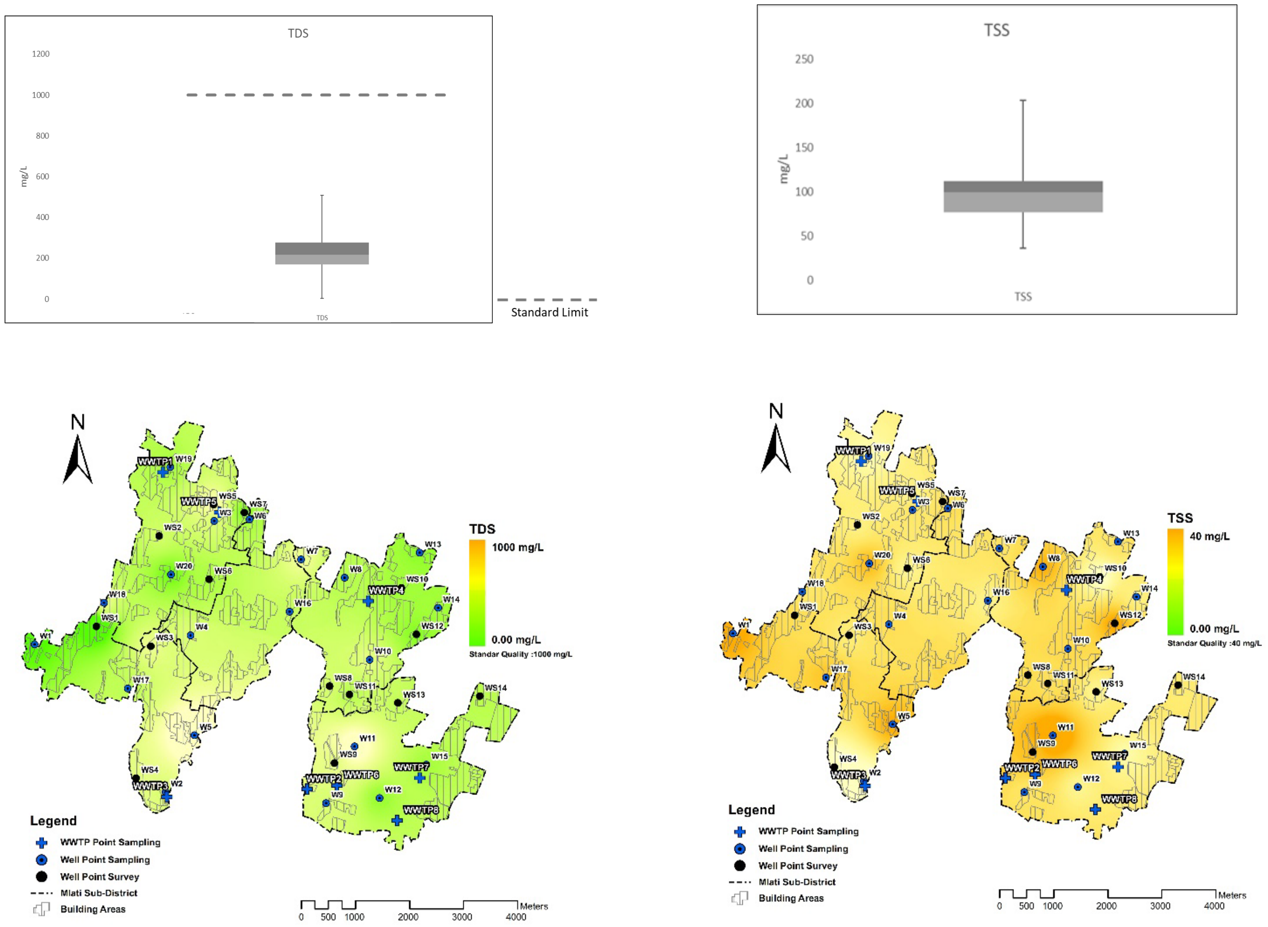

**Figure 4.** Survey of CWWTP users in the Mlati sub-district regarding (**a**) monthly fee payment amounts, (**b**) perception of subscription cost, (**c**) perception of the CWWTP operational performance, and (**d**) the perception of CWWTP service.

### *3.3. Groundwater Quality*

Overall, the groundwater monitoring data demonstrate that not all parameters met the quality standards established by Indonesian Minister of Health No. 27 of 2017 regarding requirements for groundwater quality for hygiene and sanitation purposes [32]. Groundwater temperatures were within a 3 °C range of ambient air temperature, 25.1–30.9 °C (average 28.7 °C). For pH, it ranged from 6.0 to 6.9 (average 6.29) and therefore was below the established standard of 6.5 to 8.5. All groundwater samples were odorless.

Figure 5 summarizes the results of the analysis of TDS and TSS and their concentration distribution patterns. TDS concentrations ranged between 90 and 448 mg/L (average 228 mg/L) (Figure 5a). The average TDS concentration met the water quality standard, which is 1000 mg/L. TSS concentrations varied between 41 and 204 mg/L (average 108.6 mg/L). Based on Minister of Health of the Republic of Indonesia Number 27 of 2017, the TSS standard does not include the quality parameter of groundwater.

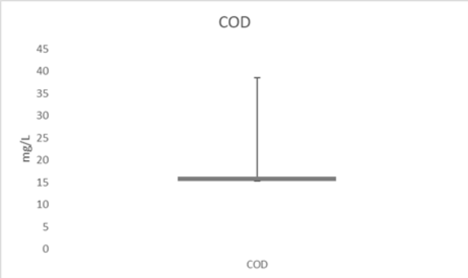
COD levels in groundwater range between 15.3 and 38.6 mg/L (average 18.2 mg/L) (Figure 6a). In Indonesia, there is no quality standard for COD in groundwater used for sanitation and hygiene purposes. In comparison to the first class of standard water quality for surface water (river and lake) according to PP No. 22 of 2021, the maximum allowable COD is 10 mg/L [33]. Meanwhile, the WHO specifies a COD standard of 40 mg/L for groundwater used for domestic purposes [34]. According to the WHO standard, the maximum concentration of COD in the groundwater (38.6 mg/L) approached the limit concentration (40 mg/L). COD concentrations were higher near almost all CWWTPs, except CWWTP3 and CWWTP4. The increased COD near most CWWTP locations can be influenced by a wide range of factors, including the graywater not being fully connected to the CWWTP or the use of infiltration wells, which increases the likelihood of pollution at the site. Another factor is the common practice of dumping graywater (washing water) into the yard. The elevated COD level may also be a result of manure use on agricultural land adjacent to CWWTP1, CWWTP5, CWWTP6, and CWWTP7.




(**a**) (**b**)

**Figure 5.** (**a**) TDS and (**b**) TSS concentration and distribution pattern.

According to the laboratory analysis and the mapping of distribution pattern (Figure 6b), ammonia ($NH_3$-N) was detected everywhere at identical concentrations (0.06 mg/L) above the method detection limit (LOD) of 0.02 mg/L. For comparison, the drinking water quality standard of Permenkes RI No. 492/MENKES/PER/IV/2010 for ammonia is 1.5 mg/L [35]. Meanwhile, the nitrite concentration in groundwater was 0.01 mg/L (LOD is 0.002 mg/L) at all locations, except for W10 (0.11 mg/L) (Figure 7a). The nitrite groundwater quality standard is 1 mg/L. Elevated nitrite concentrations, but well below standard concentration, were observed near CWWTP2, CWWTP5, and CWWTP6. Nitrate concentrations in groundwater were in the range of 0.7–37.5 mg/L (average 7.5 mg/L) (Figure 7b). Four of the twenty sampling points exceeded the permissible quality standard (10 mg/L). These sampling points were W6, W8, W9, and W10 with a concentration range of 14.9–37.5 mg/L. Typically, the highest nitrate concentrations were not found near CWWTPs.



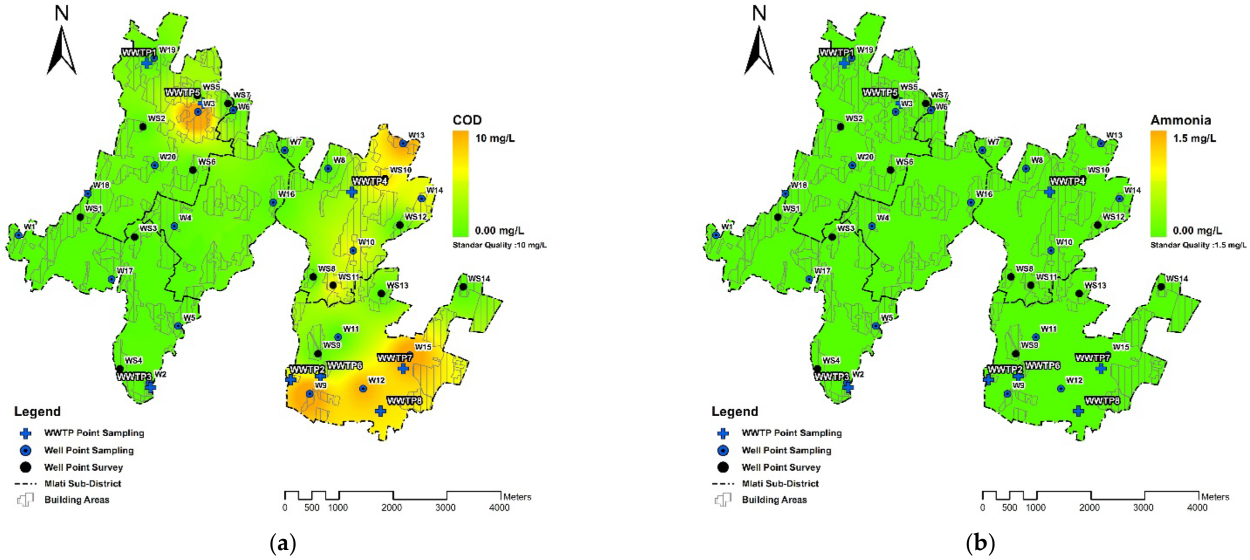
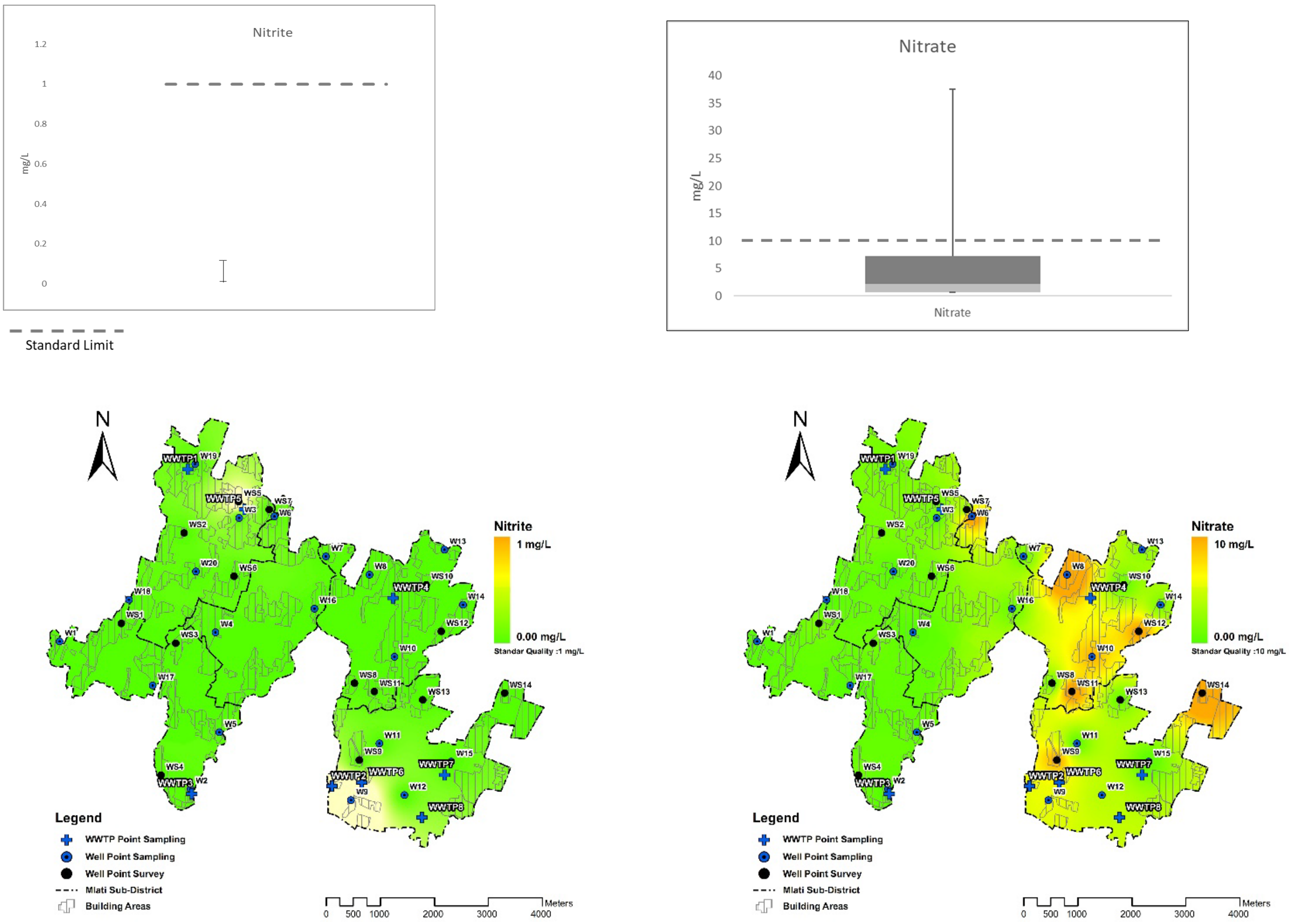




**Figure 6.** (**a**) COD and (**b**) Ammonia concentration and distribution pattern.

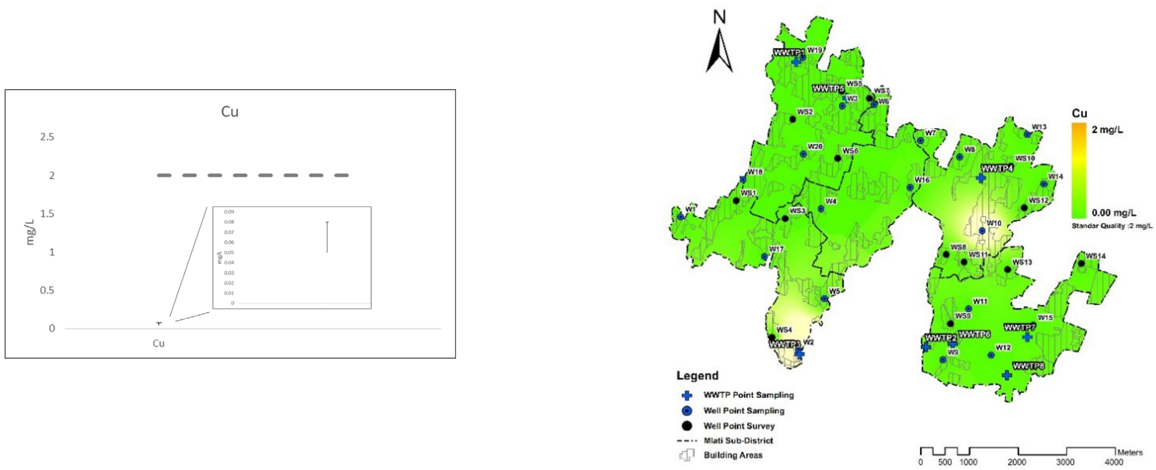
Furthermore, the heavy metal was analyzed for broad groundwater quality clearly even though it was not compared to the effluent quality of CWWTPs directly. Thirteen of twenty sampling points exceeded the groundwater standards for lead (Figure 8). Lead concentrations ranged from 0.03 to 0.67 mg/L (average 0.13 mg/L). The water quality standard for Pb is 0.05 mg/L, refer to the Ministry of Health of the Republic of Indonesia No. 32 Year 2017 for sanitation hygiene [36]. Zinc concentrations ranged from 0.05 to 0.62 mg/L (average 0.23 mg/L). At all sampling points, the Zn concentrations were less than the quality standard of 15 mg/L. The Cu concentration was consistent at 0.05 mg/L at all monitoring points except W2, which had a concentration of 0.08 mg/L. As for other water quality standards, the copper concentration was limited to 1.3 mg/L (US EPA) and 2.0 mg/L (WHO or EU) [37].

Figure 9a illustrates the concentration and distribution of oil fat in groundwater. Oil and grease concentrations ranged from 0.5 to 0.8 mg/L (average 0.6 mg/L). As with COD, there are currently no quality standards for oil and grease parameters in groundwater in Indonesia but up to 1.0 mg/L is typically considered acceptable. Figure 9b,c show the biological parameters collected from 20 wells located throughout the Mlati sub-district. For drinking water, the maximum acceptable concentration of either *E. coli* or total coliform is not detectable per 100 mL [35,38]. The concentrations of total coliform and *E. coli* in all of the tested samples exceeded the drinking water standard. The highest total coliform values were found at W5, W6, W13, W12 (1600 MPN/100 mL) while the highest concentration of *E. coli* was found at W3 (220 MPN/100 mL). Due to the extreme value of *E. coli* at W3, it is omitted from the box plot figure (Figure 9b). It is noted that the setback distance between a well and a septic tank was less than 10 m in 29% ($n$ = 10) of cases. Half of all wells ($n$ = 17) lacked drainage channels to keep polluted water away from the wellhead [39]. The depth of the wells ranged from 6 to 20 m (average 11.4 m).



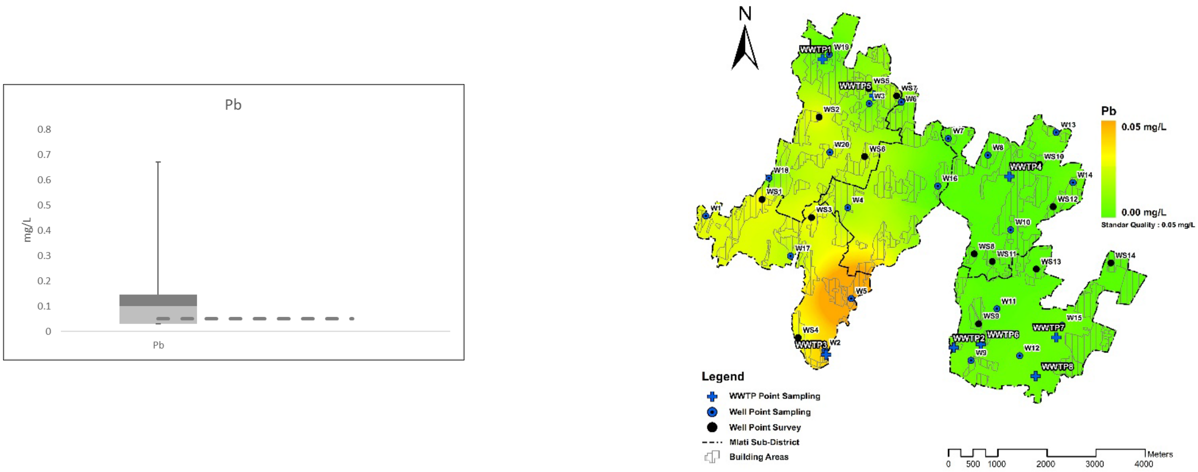

(**a**) (**b**)

**Figure 7.** (**a**) Nitrite and (**b**) nitrate concentration and distribution pattern.

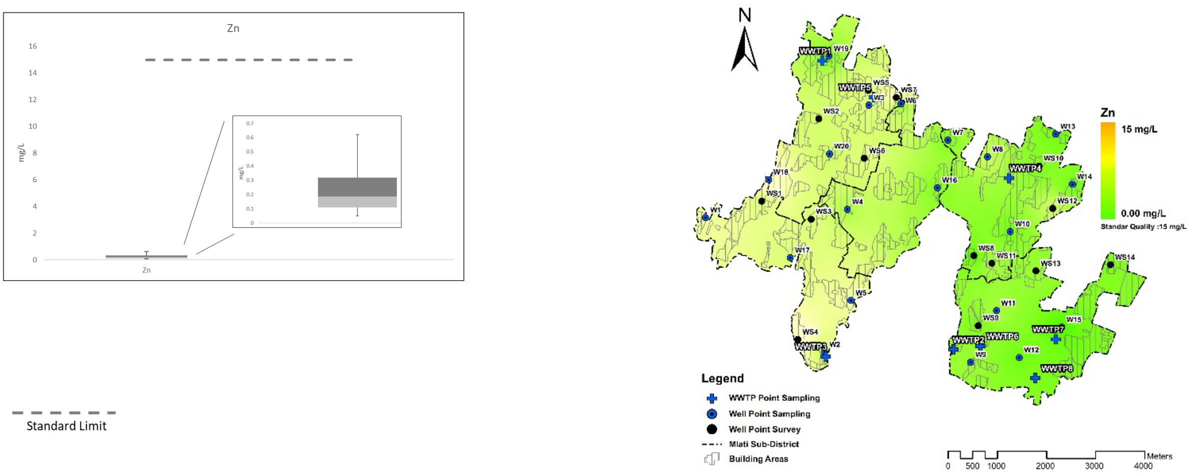



(**a**)

**Figure 8.** *Cont.*

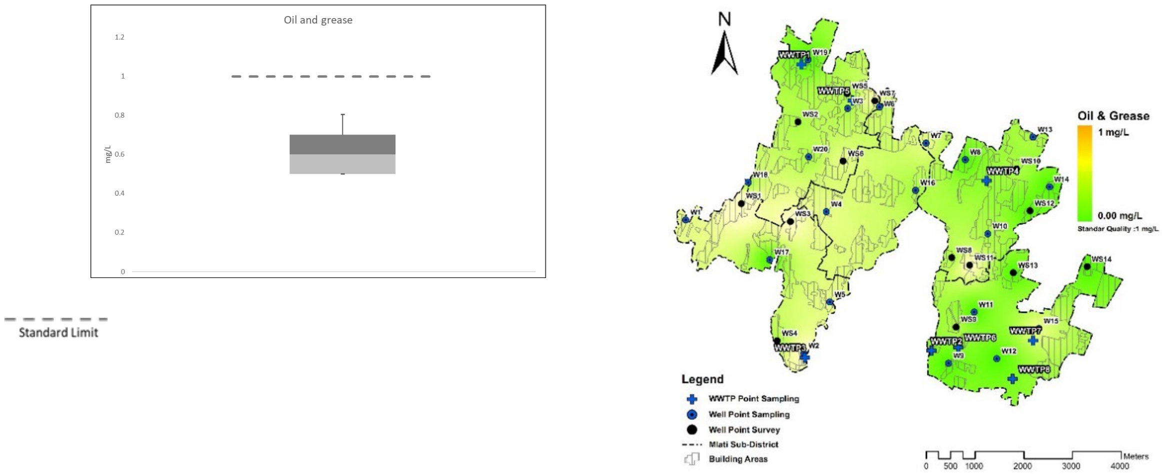



(**b**)



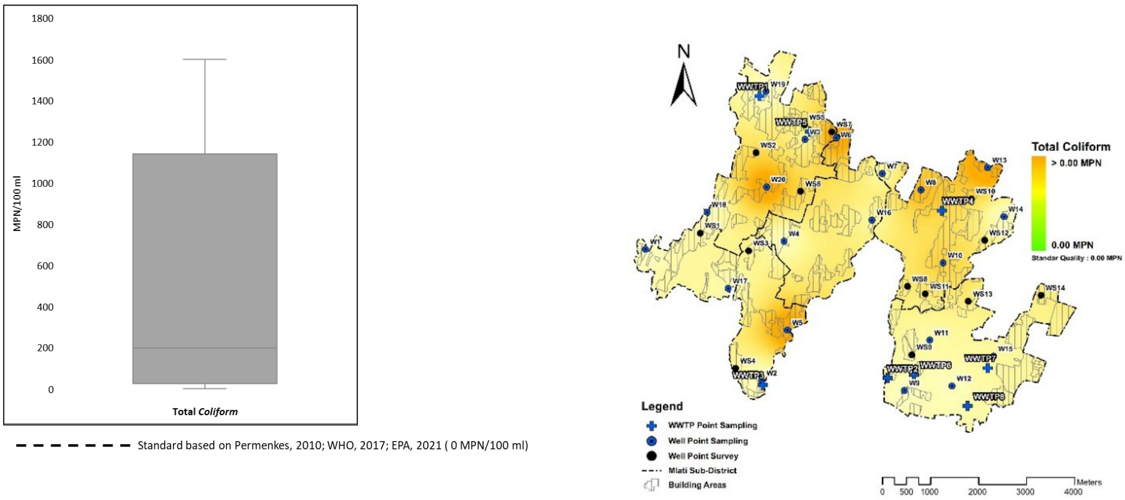

(**c**)

**Figure 8.** (**a**) Copper, (**b**) Lead, and (**c**) Zinc concentration and distribution patterns.

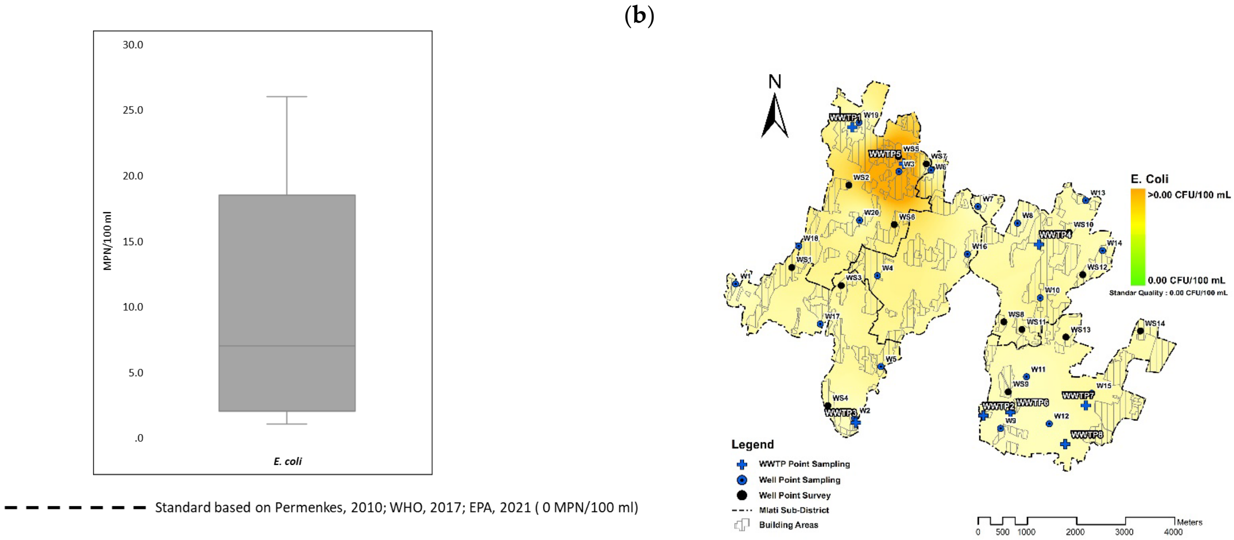



(**a**)

**Figure 9.** *Cont*.




(**b**)




(**c**)

**Figure 9.** (**a**) Oil and fat, (**b**) Total coliform, and (**c**) *E. coli* concentration and distribution pattern.

## 4. Discussion

### *4.1. CWWTP Effectiveness*

The temperature conditions in all six CWWTPs were mesophilic (20 to 40 °C range) which is considered ideal for anaerobic treatment [40,41]. Further anaerobic treatment of wastewater via methanogenesis is most effective when the pH is between 6.3 and 7.8 [42]. At the CWWTP outlets, the pH reaches a maximum of 7.19 and a minimum of 6.67 and therefore is in the ideal range of methanogenic treatment processes. If the pH conditions are neutral, the increase in hydrolysis and acidogenesis processes can result in a high efficiency of about 80% in COD removal during the anaerobic treatment process [43,44].

TSS concentrations at all CWWTP outlets exceeded the quality standard, 30 mg/L (range: 44 to 156 mg/L). Causes for the exceedances can be related to insufficient hydraulic retention time (HRT) in the Anaerobic Baffled Reactor (ABR) unit. TSS removal efficiency increases as HRT in the ABR increases. Alternatively, TSS can be derived from bio-flocs that are not heavy enough to settle before the treated water reaches the outlet. This can result in an increase in the TSS concentration at the outlet [45]. With regard to BOD, all but two CWWTPs worked properly. Most CWWTPs treat biological matter by ABR. Hence, BOD can likely be reduced in those two non-complaint systems if the ABR operational and maintenance processes were to be optimized [46]. The BOD/COD ratio indicates a waste's biodegradability. The optimal BOD/COD ratio for COD removal is between 0.48 and 0.53;

however, when the BOD/COD ratio is less than 0.3 or greater than 0.6, the removal of pollutants in wastewater is less effective [47]. In this study, the inlet BOD/COD value for each of the six WWTP points was sub-optimal (0.24 and 0.29). To remove residual organic matter from domestic waste treated with ABR, additional advanced treatment units or post treatment can be added to ensure that the concentration of parameters at the CWWTP outlet meets quality standards [48,49].

The presence of odors and blockages is one of the issues encountered during operations of some CWWTPs. The obstructions are caused by the presence of domestic waste in the pipeline carrying the domestic wastewater to the treatment plants. Clogging can impact the ABR performance and can cause the formation of hydrogen sulfide ($H_2S$) gas from the decomposition of domestic waste in the CWWTP system [50]. According to the laboratory testing, all CWWTPs, except CWWTP6, showed increasing ammonia concentration from the inlet to outlet. The anaerobic condition inside the ABR reactor indicated a not optimal process to produce methane because of the increasing of ammonia concentration. Previous research showed that a rise in ammonia levels indicates an unfavorable anaerobic environment for bacteria that decompose organic matter in aerobic environments [51,52]. Furthermore, previous research on WWTPs in several sub-districts of the Sleman regency showed total coliform concentrations at the outlet ranged between 10 and $95 \times 10^6$ MPN/100 mL [52,53], which was significantly greater than what was detected in this study.

### 4.2. CWWTP Management

This study is unique in analyzing CWWTPs using two perspectives at once, namely from the managers' and the users' perspectives. Many previous works in the same context rely mostly on how users perceive CWWTP managers' performance. Applying two perspectives, as this study did, will help to better understand CWWTP management. Most CWWTPs in the research area were built by the government, which is in line with previous findings related to the construction of such facilities in Yogyakarta and other provinces in Indonesia [54–56]. Even though they were built by the government, CWWTP users have proven to have a good sense of ownership and responsibility, as seen in their willingness to contribute. This sense of ownership and responsibility should continue to be developed by further increasing the togetherness between managers and users which in the Yogyakarta tradition is usually manifested in associations or *paguyuban* [57,58].

Most CWWTP users perceive the subscription fees as adequate, which also can be found in previous works [31,55]. The existence of CWWTPs for users is basically very helpful in reducing environmental problems. Thus, it is natural that they support the government in building CWWTPs. Evidence of such support, through financial contributions and other voluntary assistance, among others means, in the context of Yogyakarta, and many other areas in Indonesia, can be viewed from the spirit of *gotong royong*. The government and CWWTP managers can improve user support by providing more collaborative works in maintaining the facility or other relevant activities. Better communication in such programs will invite more users to be aware of CWWTPs' existence and sustainability [58,59]. Furthermore, this study and others found that CWWTPs have not been fully utilized based on their maximum capacity [60]. Thus, improving managers and government commitments to promote CWWTPs among users should be prioritized [61,62].

This study found that most CWWTP users were satisfied with CWWTP managers' performance, although some complains were still expressed. Such a finding can also be traced from previous works on CWWTPs in many areas [55]. This satisfaction could be a good indication for possible improvements among CWWTP managers. With all limitations shown in CWWTPs' effectiveness, user satisfaction should be answered by better services as well as more support from the government. CWWTP managers can learn from previous works on what to do to improve user satisfaction such as a more positive attitude, better communication concerning programs, and more community participation [63].

### 4.3. Groundwater Quality

TDS is a parameter that can be used to determine whether an intrusion or ionic contamination is better than the Electrical Conductivity (EC) value [64]. The results show that the TDS concentration in the groundwater was well under the maximum standard quality of the Minister of Health of the Republic of Indonesia Number 27 of 2017 (1000 mg/L). This is supported by the geographical condition of the study site, whereby the intrusion of a dissolved solid, especially from seawater on the flanks of Mount Merapi, is highly unlikely because there is more than 40 km distance between them. The existing of dissolved solid in the groundwater was to be expected from the local source in the Mlati sub-district.

The groundwater pH in the study area was slightly acidic on average (pH 6.29) and outside the acceptable limits. Although the study area is located in a volcanically active zone, no obvious causes were identified, and further investigations into the origin of the groundwater's acidity are needed. While average TDS (228 mg/L) met the water quality standards, the average TSS levels (108.6 mg/L) exceeded the standard of 40 mg/L at all monitoring points, except at one sampling location (W2). For comparison, TSS concentrations over 40 mg/L may begin to appear cloudy in most situations [65]. Locations with elevated levels, such as CWWTP4 located in Sendangadi Village, were typically detected in areas with the highest population densities among other regions, with up to 3288 persons per square kilometer [66]. In Indonesia, there are currently no quality standards for COD (average 18.2 mg/L) and oil and grease (average 0.6 mg/L). For comparison, the standard for oils and grease in groundwater in Sri Lanka is 0.2 mg/L [67]. The failure of local domestic wastewater treatment (on-site system) to remove oil and grease is the likely reason for the exceedances [68], but further investigations are required to confirm this source.

Ammonia and nitrate were well below the water quality standard. Although average nitrate concentrations (7.5 mg/L) were below limit, three sampling points, W10, W8, and W6 (23.4; 33.4; 37.5 mg/L, respectively), were in excess of the allowed standard quality (10 mg/L) in groundwater and require attention due to a link to long-term colorectal cancer risk in Yogyakarta. It is noted, however, that the highest nitrate concentrations were not found near CWWTPs in general. The high concentration of nitrate indicates a decomposition process of organic matter that can come from the use of fertilizers (agricultural activities), seepage from septic tank systems, contamination with untreated domestic waste, livestock activities, and so on [69,70]. Several studies show that there has been an increase in nitrate concentrations over several decades. This is due to the change in land use from open land into settlements accompanied by on-site sanitation conditions that do not meet the requirements, causing contamination of groundwater by feces [71]. High ammonia concentration ($NH_4^+$) (1–10 mmol/L) in the groundwater indicated that it was contaminated from leachate and the spilling and intrusion of domestic wastewater [72]. Complementary to this, the ammonia concentration in this study was identified to be near the limit of detection of the method. It is possible that the denitrification process in the groundwater has not yet occurred.

Under the observed slightly acidic groundwater conditions, elevated heavy metal concentrations related to leaching of naturally occurring metals from the bedrock are plausible. That is, heavy metals in groundwater may originate from Mount Merapi's volcanic activity [73]. However, prior studies suggest that leaching from the original rock only accounts for 5 to 10% of the total [74]. Besides naturally occurring heavy metal sources, select metals in groundwater, such as lead or copper, might be linked to anthropogenic activities such as uncontrolled industrial and domestic waste disposal or mining activities. The observed exceedances of lead in water might also be related to other causes, such as pipe corrosion. In general, Pb concentrations in soils in the densely populated Yogyakarta urban area are higher than in the surrounding suburban areas, presumably due to human activities [75]. Elevated Copper concentrations at levels below US EPA or WHO/EU standards were observed in several locations throughout Yogyakarta and linked to batik industry activities [76].

Confirming prior studies [25], groundwater contamination with total coliform and *E. coli* is widespread in the study area. For instance, 105 of 133 well-water samples from the Sleman regency did not meet the water quality standards for *E. coli* and total coliform bacteria [26,35,38]. Our results indicate that CWWTPs reduced bacteria concentration in the groundwater surrounding the treatment plants in some areas. The findings were supported by previous research explaining the disadvantages of ABR reactors for treating domestic wastewater. It was not possible to remove the pathogen bacteria, such as total coliform and *E. coli* [77]. The disadvantage of ABR may be a good indication of the need for a new method to remove microbiological contamination in CWWTPs. As suggested in some works, an activated sludge system and membrane bioreactor [78] could be considered for further trials in the CWWTP. Furthermore, the most pivotal matter is adding a disinfection unit right before discharge into water bodies or infiltration tanks. However, this method needs more than CWWTP managers' willingness to be implemented since the government and user involvement will be required.

## 5. Conclusions

This study suggests that CWWTPs in the study area perform well for some indicator pollutants but fail to treat others. One factor limiting the performance of CWWTPs appears linked to how the operation and maintenance of these systems is financed by the local population as users. Overcoming the lack of funding would likely result in enhanced performance of the treatment plant in some locations. Moreover, there is an indication that well performing CWWTPs are linked to improved groundwater quality in the areas surrounding these plants. However, there are too few households connected to wastewater treatment plants, and the usage of septic systems built too close to drinking water wells remains a big challenge to improving the groundwater quality in the study area. In addition, the local geology and industrial pollution affect the groundwater quality. While little can be done about the influx of geogenic pollutants, stronger governmental oversight of polluting industries should improve groundwater quality. Overall, the interaction between CWWTPs and the local groundwater is complex and often site-specific.

**Author Contributions:** Conceptualization, W.B.; methodology, W.B.; software, A.A.A.; validation, W.B., T.B. and A.A.A.; formal analysis, W.B., A.A.A., S.R., A.Y., N.I.W., A.N.L. and Y.A.; investigation, W.B., A.A.A. and S.R.; resources, W.B.; data curation, A.A.A., S.R., N.I.W. and A.N.L.; writing—original draft preparation, W.B., T.B., A.A.A., S.R., A.Y., N.I.W., A.N.L. and Y.A.; writing—review and editing, W.B., T.B., A.A.A., S.R., A.Y., N.I.W., A.N.L. and Y.A.; visualization, A.A.A., S.R., A.Y., N.I.W. and A.N.L.; supervision, W.B. and T.B.; project administration, A.A.A.; funding acquisition, W.B. All authors have read and agreed to the published version of the manuscript.

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**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to university's policy.

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