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Analysis of sanitation system and coliform number in groundwater in Wonosari District, Gunungkidul Regency, Indonesia

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Abstract. Sanitation visualizes the environment's health status, comprising housing, sewage disposal, and clean water provision. In general, sewerage can have on-site and offsite sanitation facilities. The research was conducted to characterize the sanitation system for sewage disposal, determine the water quality from biological parameters, and enumerate coliform bacteria in groundwater for every sanitation system observed in Wonosari District, Gunungkidul Regency, Indonesia. These sets of information can help detect groundwater contamination by coliform that reflects the sanitary characteristics of the sewage disposal to be further considered in sanitation management and treatment policies. The research used purposive sampling, field surveys, interviews with a questionnaire, laboratory analyses, and a descriptive-comparative design. The results showed that the sanitation system for sewage disposal at the study site consisted of individual septic tanks and wastewater treatment plants (WWTPs). In terms of quality, the coliform counts exceeded the existing standards, with the highest presence found in groundwater downstream of improperly maintained WWTPs and substandard septic tanks close to other sources of pollutants.

1. Introduction

Sanitation is a subject of concern in water resource management. When management is lacking, sanitation facilities can increase the likelihood of bacterial contamination in groundwater. It is common for many communities in rural areas and low-income urban settlements to use on-site sanitation facilities, which, in and of itself, can be a major source of pollutants. On-site sanitation collects and stores fecal matter on the same plot where it is deposited without introducing further treatments [1]. Poor sanitation systems, open defecation, and improperly maintained wastewater disposal and treatment facilities are sources of pollutants that present coliforms in groundwater. With the increasing human activities that inevitably generate more domestic waste, it is imperative to identify the characteristics of a sanitation system to determine potential groundwater contamination by bacteria.

Wonosari is the most densely populated district in Gunungkidul Regency (1158.18 people/km^2) according to BPS-Statistics of Indonesia [2]. It occupies a basin, which is a bowl-like landform enclosed by karst hills (Gunungsewu) in the south and structural hills (Batur Agung) in the west, north, and east [3]. This basin morphology forms a place where water accumulates, contributing to the abundant water resources in the district. Nevertheless, inherently, it is susceptible to water pollution because the surrounding karst hills, which make up most of the physical environment, have a thin layer of soil through which harmful substances can easily enter and taint the groundwater.

Groundwater contamination by coliforms is most likely to occur in Wonosari. Data from the Regional Environmental Status of Gunungkidul Regency in 2014 showed that all five samples of the local well water tested positive for coliforms. The groundwater samples collected in Sumbermulyo RT 01/02 (Kepek Village) and Besari RT 01/04 (Siraman Village) had the highest fecal coliform count and total coliform amounting to ≥1898/100 ml (relatively high presence).

In addition to human activities, variations in the adopted sanitation systems also regulate groundwater vulnerability to coliform contamination. Based on the data from the Public Works Service,

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the sanitation system in Wonosari District varies in service coverage, year of construction, and maintenance. In addition, potential or possible contamination differences may result from other characteristics, such as structural maintenance and distance between wells and sanitation facilities. Public Works has established sanitation development procedures based on the Indonesia National Standard SNI 2398 [4] issued by the Ministry of Public Works, including septic tank construction and a safe distance of at least 10 m from the septic tank to wells acting as clean water sources and 5 m to infiltration wells. To determine the extent to which variations in the sanitation system affect coliform contamination in groundwater, it is necessary that each type of the system is characterized and analyzed for such effect. Thus, the kind of sanitation to best prevent groundwater pollution by coliforms can be identified.

2. Data and Method

2.1. Data

The data used in the study were gathered through field surveys, sample testing in the laboratory, literature studies, and relevant agencies. The secondary data collected for the analysis included WWTPs in Gunungkidul Regency from the Department of Public Works and Housing, water quality in Wonosari District, population density from the Indonesian Statistics Agency, and sources of pollutants. The primary data consisted of information on the sanitation system's characteristics, water-table elevation at the sampled wells, and coliform count in the groundwater (through laboratory tests).

2.2. Method

A questionnaire was used in structured interviews as the research instrument to identify the characteristics of the sanitation system. In addition, other equipment like Avenza maps, field checklists, and a set of sampling tools consisting of a measuring tape, an icebox, water sample bottles, and a water checker was used. Furthermore, the Indonesia Topographic Map (RBI) of Gunungkidul at a scale of 1:25,000 was used to determine the physical condition of the study site, including roads, rivers, and administrative boundaries. Also, data from the Public Works were consulted to determine the number and location of communal WWTPs.

The sanitation system for sewage disposal was characterized using the field survey and interview results. Laboratory analysis was conducted to enumerate the presence of coliform in groundwater by testing fecal and total coliform parameters. The test results were then compared with water quality standards for sanitary hygiene in Regulation No. 32 of 2017 and drinking water quality standards in Regulation No. 492 of 2010 issued by the Minister of Health (MoH). Further, the test results of the water samples collected from the dug wells of sanitation system users were intercompared to determine which one contained the smallest to largest coliform to confirm fecal contamination in the groundwater.

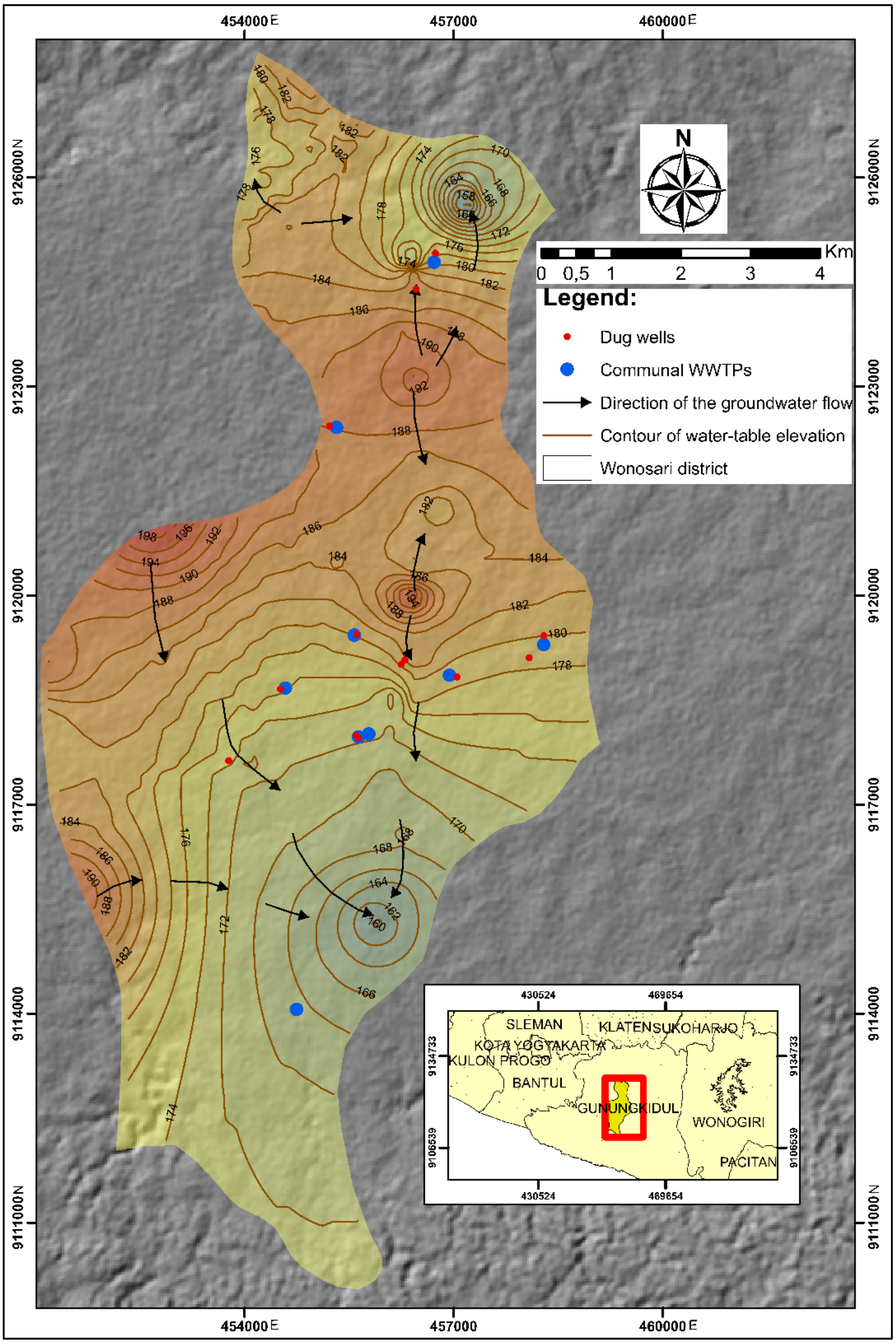

Figure 1. Map of Groundwater Sampling Points (Dug Wells) and Direction of Groundwater Flow

The purposive sampling technique determined the samples, which collects data by applying specific criteria. In this case, the criterion was as follows: the sample should represent each existing sanitation system across the district: communal, individual, and local. Therefore, groundwater samples were collected at dug wells downstream of each system (i.e., sampling unit), as shown by the direction of the groundwater flow (Figure 1). Based on the data on elevation and depth of the groundwater table, the value of the groundwater level can be seen. The data is used to map groundwater flow so that the direction of groundwater flow can be known. This process was intended to choose dug wells that accurately represented the sanitation system and enumerate coliforms present in the groundwater.

3. Results and Discussion

3.1. Sanitation Systems for Sewage Disposal in Wonosari District

Sanitation systems for sewage disposal in Wonosari District consist of various types. Generally, divided into a centralized (offsite) sanitation system and a decentralized (on-site) sanitation system.

3.1.1. Centralized or Offsite Sanitation. Centralized or offsite sanitation is a system that disposes of wastewater flows from several households into a collection channel and then a centralized treatment plant [5]. Based on the data from the Public Works, the centralized system can be found in nine WWTPs located in some of the villages in Wonosari, all of which were included as the object of observation in the research.

Further observations revealed that these WWTPs were introduced or maintained through different programs: community-based environmental sanitation (*Sanitasi Lingkungan Berbasis Masyarakat* – SLBM), community-based sanitation (*Sanitasi Berbasis Masyarakat* – SANIMAS), and Communal WWTPs. These three centralized systems had different characteristics, including system capacity, and were installed at different times (Table 1). Based on the Public Works data—supported by information from the WWTP management, the plant installation was funded and implemented by the Public Works and the Working Unit of Environmental Sanitation Development. SLBM and SANIMAS were government initiatives aiming to increase community access to proper sanitation [6].

Table 1. Sanitation system, capacity, year of construction, and maintenance funding of nine WWTPs in Wonosari District

No	Sewage Disposal System (WWTPs)	Sanitation Type	Year of Installation	System Capacity (households)	Maintenance Funding
1	WWTP Karangrejek	SLBM	2013	150	Contribution funds
2	WWTP Rusunawa Karangrejek (Flat)	Communal	2019	350	Flat management
3	WWTP Siraman	SANIMAS	2010	42	Contribution funds
4	WWTP Mulo	SLBM	2014	180	Contribution funds
5	WWTP Rejosari, Baleharjo	SANIMAS	2016	150	Contribution funds
6	WWTP Kepek I	SLBM	2013	80	Contribution funds
7	Domestic WWTP Selang V	Communal	2018	44	Contribution funds
8	WWTP Piyaman	SANIMAS	2016	150	Contribution funds
9	WWTP Karangtengah	Communal	2019	51	Contribution funds

Sources: Field Survey, 2021, and Public Works Service, 2022

Construction is an essential aspect of a building. Based on the field survey results and information from the WWTP management, the nine plants observed had a similar structure, i.e., a combination of iron frames and concrete cast. Experts were consulted in the careful planning, design, and construction of the plants, guaranteeing the physical quality of their structure more than it would be without professional involvement. In addition, construction is an aspect that significantly determines possible contamination associated with management and maintenance during the structure's operation. The district's wastewater management technology mainly combined an anaerobic baffled reactor (ABR) with an anaerobic filter (AF). The treatment chamber of ABRs consists of a sedimentation basin connected to reactors that are compartmentalized by a series of baffles to create upflows, whereas AFs are packed with layers of rocks that are larger at the bottom and increasingly smaller toward the top of the filtration chamber [7].

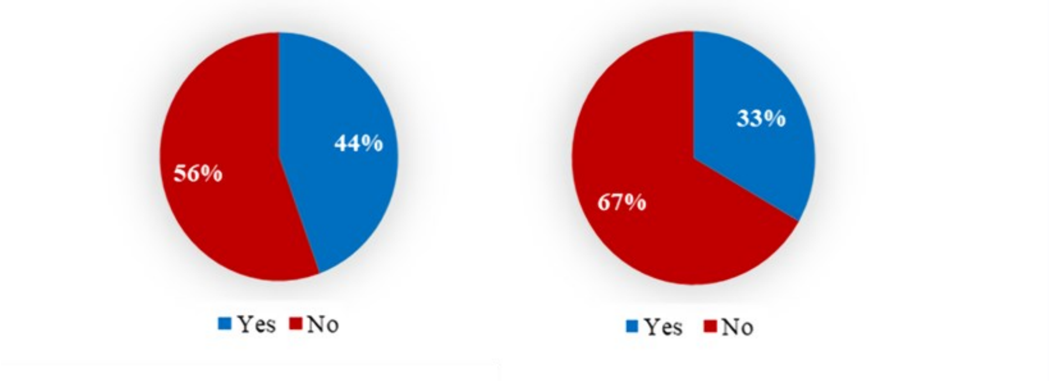

Figure 2. Percentages of water quality monitoring at the WWTP outlet (left) and routine inspection on WWTP condition (right)

Wastewater is treated at WWTPs to remove contaminants and discharge the remaining water, called effluent, back into water bodies or the environment without causing pollution [8]. It is thereby imperative to monitor water quality at the plant outlet. Observations and additional information from the WWTP management revealed that such monitoring had been conducted at four of the nine plants (44%) but not at the remaining five (56%) (Figure 2-left). In addition, only three (33%) were routinely checked for their most current conditions by responsible agencies (Figure 2-right). From these facts, it can be inferred that damages such as leaks and clogged drains may not be detected early. More often than not, reports are made to the office when the affected community is experiencing unpleasant odor and puddles are observed around the plant, which then prompts an inspection. Monitoring of water quality at the outlet measures to what extent the installed plant successfully treats wastewater and, thus, ensures that the effluent can be returned to water bodies or the environment without harming environmental sustainability.

Using a centralized sanitation system to treat wastewater before its disposal in the environment can reduce the potential for water pollution, provided that proper management and maintenance are implemented. The maintenance in question can include desludging, draining, repairing pipes, and monitoring water quality at the WWTP outlets. According to the detailed technical planning guidelines for sludge treatment facilities, the treatment tank must be desludged and drained at least once in three years [9]. However, field observations and interviews with the management found that the WWTPs in the district were not desludged and drained regularly. Moreover, some had never been desludged. It was also found that only three of the nine sampled plants were routinely desludged and drained, namely WWTPs Rusunawa Karangrejek and Kepek I (once a year) and Mulo (every three years). In conclusion, because of the required routine desludging, all the observed WWTPs in Wonosari District do not comply with the guidelines, except for Rusunawa Karangrejek, Kepek I, and Mulo.

Irregular desludging and lack of proper, periodic maintenance can cause problems, e.g., drain leaks, clogging, and unpleasant odor. Leaks are the leading cause of groundwater pollution [10]. Furthermore, poor maintenance can disrupt the plant's capacity to treat wastewater, rendering this function less than optimal and potentially increasing the risk of bacterial contamination in the water and the environment.

3.1.2. Decentralized or On-site Sanitation. Decentralized or on-site sanitation uses a disposal and treatment system located in the vicinity of where the wastewater is generated without conveying it to centralized treatment sites or receiving water bodies [5]. An individual septic tank is an example of on-site sanitation adopted in Wonosari. The working principle of a septic tank involves a very slow wastewater flow that allows solids like fecal matter to settle in the tank, thus increasing the opportunity for anaerobic microbes to decompose the organic matter [11]. This naturally occurring process can separate solids in the form of stable mud from liquids.

Proper and healthy sanitation contributes to public health and environmental sustainability. A sanitation facility is considered adequate if it meets these health requirements: the facility is used by one household or together with certain other households, equipped with toilets with a built-in gooseneck trap, and connected to a final disposal site of fecal matter such as a septic tank or WWTP [12]. Based on the field survey findings, the inlets of all the eight observed septic tanks were toilets with gooseneck traps, complying with the standards for proper sanitation (Table 2).

Table 2. Toilet types and septic tank constructions

No	Locations	Toilet Designs	Septic Tank Constructions
1	Karangrejek Subvillage	Gooseneck traps	Stone, cast top, with filters
2	Wareng Village	Gooseneck traps	Stone, cast top
3	Rejosari, Baleharjo	Gooseneck traps	Stone, cast, filters
4	Ringinsari, Wonosari	Gooseneck traps	Brick
5	Wonosari Village	Sitting toilets	Stone, filters made from stiff Arenga fibers
6	Selang	Gooseneck traps	Stone, cast top
7	Karangtengah	Gooseneck traps	Stone, cast top
8	Karangtengah	Gooseneck traps	Stone, cast top

Source: Field Survey, 2021

In addition to toilet design, septic tank construction is another aspect contributing to the properness of a sanitation system. The septic tanks in the district were mostly made from stones, bricks, and a cast top. Some were only used to dispose of and store sewage without removing the solids from liquids because they did not have filters or filter beds. Only three of the eight septic tanks observed (37%) were equipped with advanced processing, i.e., filtration. Based on information from the residents, filters were not added to the tank to minimize construction costs. An effluent still contains several organic parameters [11]; therefore, without the needed further processing, it increases the potential for water pollution, primarily due to seepage from the septic tank. This explains why offsite sanitation (i.e., WWTPs) technically poses a lower risk to the environment than on-site sanitation, such as septic tanks [1], mainly because the former is equipped with wastewater treatment technology, and related agencies directly supervise its construction.

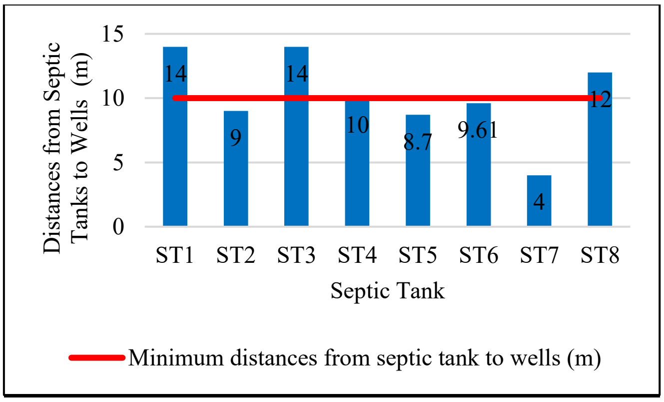

Figure 3. Distances from the Eight Septic Tanks Observed to the Nearest Wells

Per the SNI 2398 [4], the Public Works established standardized sanitation construction procedures that include septic tank construction and a safe distance of at least 10 m from water wells and 5 m from infiltration wells. During the field survey, it was found that the septic tanks were installed at varying distances from the dug wells used to meet the local domestic water needs (Figure 3). Also, only 37% of the eight sampled septic tanks were installed more than 10 m or at a safe distance from the nearest dug wells. Therefore, around 63% do not meet the above provision, i.e., > 10 m to wells. The distance between septic tanks and the nearest buildings, wells for clean water sources, and rain infiltration wells should be carefully considered in planning the construction [13] because the closer the septic tank is installed to a well, the greater risk of contamination it poses, especially by coliform bacteria [14].

Based on the survey results, all the septic tanks observed were never drained or desludged. In addition, interviews with the residents revealed no routine inspection of their condition and water quality monitoring at the surrounding wells. This situation can have a negative impact on the future. According to the construction procedures in SNI 2398, a septic tank should be drained or desludged once every 2–5 years, assuming a family of five members uses it with sludge sediment forming at 30–40 L/person/year.

Draining or desludging reduces the potential for leaks, clogging, and explosion due to the decomposition by-products, i.e., gas [15]. All the septic tanks in the district are never drained or desludged; thus, it is highly likely that bacteria-containing water and mud from tanks with permeable bottoms and without wastewater filtration have seeped into the ground. Septic tanks with permeable bottoms can contaminate waters in downstream wells, especially if both are located less than 10 meters from each other [16].

3.2. Groundwater Quality Based on Coliform Count in Wonosari District, Gunungkidul Regency

Coliforms, including fecal coliform and total coliform, are the biological parameters of water quality. In addition, based on the MoH Regulation No. 32 of 2017, fecal coliform or *E. coli* and total coliform are mandatory biological parameters to check to determine whether or not a water body is suitable for sanitation and hygiene purposes and, in another regulation (No. 492 of 2010), drinking water. Furthermore, per Regulation No. 32 of 2017, sanitation and hygiene purposes include using water to maintain personal hygiene, such as bathing, teeth brushing, and washing food ingredients, eating and cooking utensils, and clothes. Water with this level of quality can also be used as raw water for drinking water.

Table 3. Coliform Count of the Well Water Samples in Wonosari District

No	Sample Codes	Fecal Coliforms (MPN/100 mL)	Total Coliforms (MPN/100 mL)
1	S1	4.5	49
2	S2	540	>1600
3	S3	11	130
4	S4	350	1600
5	S5	11	110
6	S6	33	79
7	S7	110	>1600
8	S8	920	>1600
9	S9	170	>1600
10	S10	7.8	49
11	S11	>1600	>1600
12	S12	540	>1600
13	S13	17	49

Source: Laboratory Test Results, 2021

Based on the laboratory analysis, all the water samples collected from the dug wells were contaminated with high coliform levels (Table 3). Per Regulation No. 32 of 2017, clean water for daily use or sanitation and hygiene purposes can contain a total coliform of <50 MPN/100 mL and 0 MPN/100 mL fecal coliform. With a range of 4.5 to >1600 MPN/100 mL, the fecal coliform levels of all the test samples far exceeded the water quality standard. In addition, three samples had a total coliform of 49 MPN/100 mL or only one point lower than its maximum acceptable presence (50 MPN/100 mL). The high coliform count is attributed to the physical condition of the area surrounded by karst hills with a thin layer of soil, which allows contaminants to easily seep into and pollute groundwater [3]. Moreover, the presence of pollutant sources, e.g., cattle pens, near the wells exacerbates the risk of contamination. In addition, improperly managed domestic wastewater can also increase the number of coliforms in groundwater.

Per the MoH Regulation No. 492 of 2010, water is considered suitable for drinking if it contains no coliforms (fecal and total coliform = 0 MPN/100 mL). Because the laboratory test returned with high coliform counts (Table 3), all the samples did not meet the drinking water requirements. In conclusion, based on the coliform parameter, the groundwater in the district has poor quality, which corresponds to the Regional Environmental Status of Gunungkidul Regency in 2014.

3.3. Groundwater-Contaminating Coliform Counts in Each Sanitation System in Wonosari District, Gunungkidul Regency

The waste disposal system in Wonosari District consists of a centralized sanitation system such as WWTPs and decentralized or offsite sanitation in the form of septic tanks. The presence of coliforms in groundwater in each sanitation system was enumerated from the samples collected at the dug wells of the system users. The test results showed varying concentrations of coliforms (Table 4). The highest total coliforms, >1600 MPN/100 mL, were detected in the dug wells downstream of WWTPs Piyaman, Karangrejek, and Selang. The samples with the highest concentrations of fecal coliforms were the dug wells downstream of WWTPs Piyaman (>1600 MPN/100 mL), Karangrejek (540 MPN/100 mL), and Selang V (170 MPN/100 mL). The high coliform levels in the well water are caused by the physical environmental condition and poor maintenance of the sanitation system.

Table 4. Coliform Counts in the Groundwater Samples of the WWTP Users (in MPN/100 mL)

Dug Well Locations	Sanitation System	Fecal Coliform	Total Coliform
Karangrejek	WWTP Karangrejek	540	>1600
Siraman	WWTP Siraman	11	130
Kepek	WWTP Kepek RT I	33	79
Selang	WWTP Selang V	170	>1600
Piyaman	WWTP Piyaman	>1600	>1600

Source: Analysis Results, 2022

WWTP Piyaman was built in 2016 to accommodate 150 households, but this large system capacity and construction made from sturdy iron frames and cast were not complemented by sufficient management and maintenance. Also, the survey results showed that this plant had never been drained or desludged since its construction. According to the detailed technical planning guidelines for sludge treatment facilities, the treatment tank should be drained and desludged at least once in three years [9]. However, this minimum frequency of necessary maintenance was not met at WWTP Piyaman. In addition, the water quality and sanitation system were not monitored regularly. During the interviews, it was revealed that the residents around this plant often experienced unpleasant odor, clogged drains, and leaks and saw lots of mosquitoes.

The laboratory test results showed that the well water downstream of WWTP Karangrejek had a high number of coliforms: fecal coliform of 540 MPN/100 mL and total coliform of > 1600 MPN/100 mL. The tank had been drained only once since its construction in 2013. As a result, some problems that often occurred were pipe leaks, unpleasant odor, and clogging. Also, there had been no routine checks and monitoring of water quality and no assistance from related agencies. The observed well was located only 6 m from or very close to WWTP Karangrejek. Wastewater seepage from the leaking tank and the poorly maintained plant are believed responsible for the high coliform presence in the well water.

The laboratory test results showed the lowest coliform count at the dug well downstream of WWTP Kepek I. The fecal coliform was 33 MPN/100 mL, and the total coliform was 79 MPN/100 mL. WWTP Kepek I was among the plants receiving the best care and management in the district. Based on the observation and survey findings, the tank was drained or desludged once a year, complying with the WWTP treatment guidelines. This plant was built in 2013 to accommodate 80 households and was routinely inspected (once a year) by related governmental services. Records showed that no pipe leak was recorded since its construction. The sewage treatment system in this plant was also monitored regularly, during which a solution consisting of molasses, yeast, and EM4 as nutrients for the decomposing bacteria was added. As a result of this maintenance, the sewage treatment operates optimally and potentially reduces the risk of groundwater contamination. It can be inferred from these findings that a relatively low coliform count is associated with a properly maintained WWTP.

Compared to WWTPs, individual septic tanks (decentralized or on-site sanitation system) are more common in the district. The laboratory test results showed varying concentrations of coliforms in the water samples (Table 5). Fairly high coliform counts were detected in Wonosari, Karangtengah 1, and Wareng Villages, whereas relatively low coliform levels were found in Karangrejek, Baleharjo, Selang, and Karangtengah 2. These tanks were installed at varying distances to the sampled wells.

Table 5. Coliform Counts in the Groundwater Samples of the Individual Septic Tank Users

Well Locations	Sanitation System	Distance from Septic Tank to Well (m)	Fecal Coliform (MPN/100 mL)	Total Coliform (MPN/100 mL)
Karangrejek	Individual Septic Tank	14	4.5	49
Wareng	Individual Septic Tank	9	350	1600
Baleharjo	Individual Septic Tank	14	11	110
Wonosari 1	Individual Septic Tank	10	110	>1600
Wonosari 2	Individual Septic Tank	8.7	920	>1600
Selang	Individual Septic Tank	9.61	7.8	49
Karangtengah 1	Individual Septic Tank	4	540	>1600
Karangtengah 2	Individual Septic Tank	12	17	49

Source: Analysis Results, 2022

Based on the data from the laboratory test (Table 5), the well water with the least coliform presence, i.e., in Karangkejek Village, was located 14 m from the septic tank. The fecal coliform was 4.5 MPN/100 mL, and the total coliform was as high as 49 MPN/100 mL. According to SNI 2398, apart from a distance, the number of coliforms in the well is also influenced by well and septic tank constructions. The well at Karangkejek had watertight walls, and the septic tank was made from stone and cast top and equipped with a filter composed of fibers and stones. In addition, no other pollutant sources affected this well.

The well with the highest coliform count was found in Wonosari Village. It was downstream of several pollutant sources, i.e., WWTP at the Wonosari Market and other domestic wastes, potentially contaminating the groundwater observed easily. In addition, Wonosari Village is the center of activities in Gunungkidul and has a high population density. For these reasons, a large amount of waste is generated.

The presence of other pollutant sources can increase the potential for groundwater pollution. For instance, the well sample in Karangtengah 1 Village contained 540 MPN/100 mL of fecal coliforms, and the total coliform amounted to >1600 MPN/100 mL, indicating bacterial contamination. In this location, the distance between the well and the septic tank was only 4 m or far from the minimum distance set in the SNI (10 m). Moreover, the septic tank used was never drained or desludged and checked regularly, and some sewerage was clogged. Cattle pens located about 1 m from the well also contributed to the high contamination by coliforms.

WWTPs for waste disposal and treatment are technically better in minimizing water pollution than individual septic tanks. The reason is that the plants treat the wastewater with sufficient technology and system so as not to pollute the environment [17]. In contrast, on-site sanitation, which generally accommodates and stores fecal matter at the place where it is generated without applying further processing like filtration [1], poses a higher risk of bacterial contamination. Nevertheless, installing WWTPs does not guarantee low pollution. This is evident in the laboratory test results, which suggest that some of the plants in the district have not been able to reduce bacterial contamination in groundwater. The main factor precluding the optimal operation of a WWTP is poor management and treatment after its construction. Poor sanitation systems, open defecation, and improperly maintained wastewater disposal and treatment facilities are some sources of coliforms that contaminate groundwater [1].

4. Conclusion

The sanitation systems for sewage disposal in Wonosari District consist of offsite sanitation such as communal wastewater treatment plants (WWTPs) and on-site sanitation in the form of individual septic tanks. These systems have different characteristics, including post-construction management and maintenance. Based on the field survey findings, only one-third of the WWTPs are inspected and drained or desludged regularly, and water quality monitoring is conducted at only four of the nine plants observed. In addition, the coliform counts in the district's groundwater have exceeded their maximum allowable presence, as specified in the Minister of Health Regulations No. 32 of 2017 and No. 492 of 2010. Groundwater samples with high coliform counts are found in the dug wells downstream of poorly maintained WWTPs, very close to substandard individual septic tanks with poor management, and near other sources of pollutants such as livestock pens.

References

[1] Lawrence A R and Macdonald D 2001 *Guidelines for Assessing the Risk to Groundwater from On-Site Sanitation* (UK: British Geological Survey).
[2] BPS-Statistics of Gunungkidul Regency 2021 *Kabupaten Gunungkidul dalam Angka 2020* (Jakarta: Badan Pusat Statistik).
[3] Kurniawan A and Sadali M I 2015 *Keistimewaan Lingkungan Daerah Istimewa Yogyakarta* (Yogyakarta: UGM Press).
[4] BSN-National Standardization Agency of Indonesia 2017 Standar Nasional Indonesia (SNI) 2398:2017 tentang Tata Cara Perencanaan Tangki Septik dengan Pengolahan Lanjutan (Jakarta: Badan Standardisasi Nasional).
[5] Fajarwati A 2000 Perencanaan Sistem Penyaluran Air Buangan Domestik Kota Palembang (Studi Kasus: Kecamatan Ilir Timur I dan Kecamatan Ilir Timur II), *Thesis* ITB Bandung.
[6] Directorate General of Human Settlements 2015 *Rencana Strategis Direktorat Jenderal Cipta Karya Tahun 2015-2019* (Jakarta: Ditjen Cipta Karya Kementerian PUPR).
[7] Kurnianingtyas E Prasetya A and Yuliansyah A T 2020 Kajian Kinerja Sistem Instalasi Pengolahan Air Limbah (IPAL) komunal (Studi Kasus: IPAL Komunal Kalisong, Kelurahan Sembung, Kecamatan Tulungagung, Kabupaten Tulungagung, Jawa Timur) *Media Ilmiah Teknik Lingkungan* (5) 62-70.
[8] Pranajaya I 2019 *Apa Itu IPAL Komunal dan Apa Manfaatnya* (Aceh: Sistem Informasi Database Infrastruktur Kabupaten Aceh Tamiang).
[9] Directorate of Environmental Sanitation Development (PPLP) 2019 *Pedoman Perencanaan Teknik Terinci Instalasi Pengolahan Lumpur Tinja* (Jakarta: Direktorat PPLP Kementerian PUPR).
[10] Sasmito B 2014 Sistem Sanitasi dan Kualitas Air Sumur Dangkal di Kabupaten Sumenep

Rekayasa Teknik Sipil (3) 166-172.
[11] Sudarmadji 2014 Tangki Septik dan Peresapannya sebagai Sistem Pembuangan Air kotor di Permukiman Rumah Tinggal Keluarga *Jurnal Teknik Sipil* 9(2) ISSN 1907-6975.
[12] BPS-Statistics of Gunungkidul Regency 2020 Persentase Rumah Tangga yang Memiliki Akses terhadap Layanan Sanitasi Layak (Jakarta: Badan Pusat Statistik).
[13] Nurhidayat A 2009 Strategi Pengelolaan Air Limbah Domestik Dengan Sistim Sanitasi Skala Lingkungan Berbasis Masyarakat di Kota Batu Jawa Timur *Prosiding* Seminar Nasional Manajemen Teknologi X.
[14] Sapulete M 2010 Hubungan Antara Jarak Septic Tank ke Sumur Gali dan Kandungan Escherichia Coli dalam Air Sumur Gali di Kelurahan Tuminting, Kecamatan Tuminting, Kota Manado *Jurnal Biomedik* (2) 179-186.
[15] Pujari N 2007 Sistem Sanitasi dan Kualitas Air Sumur Dangkal di Kabupaten Sumenep *Rekayasa Teknik Sipil* (3) 166-172.
[16] Mardikanto A 2020 *Hati-Hati Tangki Septik Meledak* (Jakarta: National Water & Sanitation Information Services).
[17] Hermawan T 2010 Pengaruh Sanitasi Air Terhadap Kesehatan Lingkungan Ditinjau Secara Bakteriologis: Kasus Penyediaan Air Bersih Di Kecamatan Guguk Panjang Kota Bukittinggi Propinsi Sumatera Barat *Master Thesis* Pascasarjana Universitas Gadjah Mada.

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