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SPATIAL ANALYSIS OF MICROBIOLOGICAL CONTAMINANTS BASED ON SANITARY HYGIENE OF DRINKING WATER DEPOTS IN TANGERANG CITY IN 2024

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Abstract

Introduction: *Potable water needs to satisfy quality criteria for microbiological, chemical, and physical. Consuming water that fails to comply with established quality standards can lead to illnesses, including diarrhea. In Tangerang City, based on environment-related disease counseling data from 2024, diarrhea had the highest number of cases. The study examined the influence of DAM sanitary hygiene on the microbiological quality of refilled potable water and to map the distribution of DAM in Tangerang City in 2024.* ***Methods:*** *The study employed a quantitative analytic observation with a cross-sectional method and a secondary data analysis (SDA) with a geographic information system (GIS). Independent variable in this study is the assessment results of the sanitary hygiene DAM and dependent variable is the microbiological quality laboratory test result. The sample consisted of 104 DAM across Tangerang City. Data analysis utilized the Chi-square and binary logistic regression tests. Spatial analysis for thematic map creation was performed using QGIS.* ***Results and Discussion:*** *The results showed that 72.1% of DAM met the sanitary hygiene requirements but 63.5% still had microbiological contaminants. Statistical test results showed that the sanitary hygiene of DAM had a significant partial effect on the microbiological quality of drinking water with a p-value=0.002 ($p<0.05$).* ***Conclusion:*** *The study concluded that the sanitary hygiene of DAM affects the microbiological quality of drinking water. Other variabels outside the assessment aspects also contribute, such as a contact time of UV light or disinfection equipment, maintenance of filters, and water source quality.*

INTRODUCTION

Potable water is one of the absolute necessities for every individual to maintain body fluid balance and support survival (1-2). As high as 43.62% of the Indonesian population rely on *Air Minum Isi Ulang (AMIU)* refers to refill drinking and *Air Minum Dalam Kemasan (AMDK) refers to* bottled drinking water (3). AMDK is relatively expensive, and therefore AMIU is more attractive to the public (4-5). In Indonesia, *Depot Air Minum (DAM)* refers to Drinking Water Refill Station process raw water into drinking water that can be directly consumed and sold in bulk to consumers, hereinafter referred to as AMIU (6-7). To purify drinking water, DAM commonly use methods such as ultraviolet (UV) light, ozonation, distillation, microfiltration, carbon filtration and reversed osmosis (8).

The increasing public interest in consuming AMIU has led to the rapid growth in the DAM business (9). However, this condition requires close attention because drinking water from DAM is prone to contamination due to poor sanitation and hygiene practices, as well as suboptimal processes for processing, storing, and distributing water (10-11). Therefore, DAM must meet sanitary hygiene requirements related to personnel, facilities, and equipment in the management of drinking

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water to ensure quality. In Indonesia *Formulir Inspeksi Kesehatan Lingkungan (IKL)* refers to The Environmental Health Inspection Form to assess the sanitary hygiene of DAM is regulated by the Regulation of the Ministry of Health No 14 of 2021.

According to the Regulation of the Ministry of Health No. 2 of 2023, which implements Government Regulation No. 66 of 2014 regarding Health, drinking water, with or without treatment, must meet health requirements to be safe for direct consumption (12). The standards include microbiological, chemical, and physical parameters (13). Consuming water that fails to comply with established quality standards can lead to illnesses, including diarrhea (6), often caused by poor microbiological quality of drinking water (7). Mandatory parameters for the microbiological quality of drinking water include *Escherichia coli* and total coliforms, with a maximum allowable concentration of 0 CFU/100ml each (12). Coliform bacteria indicate the possible presence of other bacteria that can affect health (7), and their presence signifies the existence of toxigenic microorganisms that pose health risks (14). *Escherichia coli* is a type of coliform that can cause gastrointestinal diseases such as diarrhea and vomiting if present in large numbers in the human body (15-16).

Tangerang City, with a population of 1,912,679 people in 2023, reported that 83.18% of households used AMIU and AMDK as their main source of drinking water (17). According to data from the annual report of the health office of Tangerang City in 2024, a total of 556 drinking water kiosks were operational in the city. In the same year, the number of diarrhea cases reached 43,050. Based on environment-related disease counseling data from 2024, diarrhea had the highest number of cases, with 936 counseling sessions conducted. The contamination of AMIU poses a significant global public health risk, as it can lead to waterborne diseases caused by bacteria such as E.coli and coliforms, which are linked to inadequate sanitation and hygiene practices. This issue is particularly critical in developing countries where access to safe drinking water remains limited, and regulatory oversight may be insufficient.

Based on previous studies, it has been shown that the sanitary hygiene of DAM has a correlation with the microbiological quality of potable water (18). The location and equipment of DAM are also directly linked with coliforms' presence in drinking water (7). In addition, research conducted in Tangerang City revealed a relationship between the completeness of sanitation facilities and personal hygiene with the number of bacteria in drinking water (19). A preliminary study by the researchers showed that there are inconsistencies between the sanitary hygiene conditions of DAM and the results of microbiology tests. For example, certain amount of AMIU did not meet the microbiological quality requirements while the sanitary hygiene conditions of the DAM are decent, and vice versa.

To facilitate the visualization of DAM conditions in Tangerang City, the researchers intended to develop a thematic map using a geographic information system (GIS) approach. The map will illustrate DAM based on sanitary hygiene and microbiological water quality, as well as highlighting the discrepancies between the two indicators. The spatial analysis in this study was based on data regarding the hygiene and sanitation aspects of DAM as well as microbiological quality of potable water. Thus, the thematic map not only serves as a tool for identification of high-risk areas, but also as a means of analyzing the potential for causal factors outside the DAM sanitary hygiene assessment instrument that can affect drinking water quality. In addition, the thematic map can be used to review the effectiveness of the sanitary hygiene assessment parameters in the IKL-DAM Form that has been used so far. This can form the basis for improving the IKL-DAM instrument as well as policy adjustments in controlling the quality of refilled drinking water.

The purpose of this study is to analyze the effect of sanitary hygiene of DAM on the microbiological quality of refilled drinking water and to map the conditions of microbiological contaminants based on the sanitary hygiene of DAM in Tangerang City in 2024. The novelty of this study lies in the creation of a thematic map of the distribution of microbiological contaminants of drinking water based on the sanitary hygiene of DAM in Tangerang City in 2024. Despite the inconsistencies observed in the correlation between sanitary hygiene and microbiological quality, the thematic map can be used as a strategic tool in supporting policy-making and evidence-based decision-making to supervise and improve service quality and quality in drinking water depot businesses. By creating a thematic map of contamination distribution, the research offers a strategic tool for targeted policy-making and resource allocation, supporting efforts to improve water safety at both local and broader levels.

METHODS

This research utilized a quantitative approach through secondary data analysis (SDA) in addition to the geographic information system (GIS)-based spatial analysis. It utilized an analytic observational method with a cross-sectional research design. The analysis of data in this study included the Chi-square test. The test was used to determine the relationship between variables and the binary logistic regression test to examine the impact of the independent variables on the dependent variable. Statistical tests were carried out using IBM SPSS Statistics 24 software. GIS spatial analysis of the thematic map was carried out using Quantum GIS (QGIS) software version 3.34.12. Mapping was carried out by combining the Tangerang City regional map database and entering the coordinates of the dams, and assigning symbols to the IKL data and microbiological water quality data for each dam that was sampled for research.

The study took place in Tangerang City, Banten Province, which is geographically located between 106°36'-106°42' east longitude and 6°6'-6°13' south latitude. Tangerang City covers a total area of 178.35 km² and consists of 13 districts, 104 urban villages, and 39 public health centers. The research was conducted from December 2024 to February 2025 at the Tangerang City Health Office. The study population consisted of all 565 registered DAM in Tangerang City in 2024, as reported in the Annual Report of the Health Office. Sample size calculation is done using Two-sample situations: Hypothesis test for two population proportions (two-sided test) or Hypothesis Test for 2 Population Proportions. The results of calculating the sample size with the values of P1 and P2 based on previous research (20-21), obtained a minimum sample size of 97 DAM. To represent the entire Tangerang City, a total of 104 samples were selected: Inclusion criteria included: 1) the DAM was still operating during the data collection period, 2) it was located in Tangerang City, 3) it had not yet obtain a *Sertifikat Laik Higiene Sanitasi* (SLHS), and 4) the operator agreed to undergo the IKL assessment and water sampling. The quota sampling technique was utilized, and based on the quota, one sample was taken from each village. Sampling was carried out by the sanitarians from the public health centers (*Puskesmas*) in each area.

This independent variable in this study is the sanitary hygiene of DAM, which includes the sanitary hygiene aspects related to handlers, buildings, premises, and equipment. Data were collected using the IKL-DAM form, referring to Ministry of Health Regulation Number 14 of 2021. The measurement method involved reviewing documents of the IKL-DAM assessment results. Results were considered acceptable if the total score of DAM sanitary hygiene was ≥80.00 (22). The dependent variable is the microbiological quality of potable water, specifically the presence of *E.coli* and total coliforms. Data were collected using laboratory test result sheets from Tangerang City's Regional Health Laboratory (Labkesda), which refers to Ministry of Health Regulation Number 2 of 2023. Microbiological quality was deemed acceptable if the total content of *E.coli* and coliform levels were 0 CFU/100ml (12).

RESULTS

Sanitary hygiene assessment of DAM is an attempt to mitigate the risk of drinking water pollution from handlers, buildings, premises, and equipment of DAM to ensure that potable water is safe to be consumed. The IKL-DAM assessment includes inspection of both the outer area (location and external design) and the inner area (internal design of buildings and facilities, handlers, equipment, and raw water). The results of the univariate analysis of sanitary hygiene of 104 DAM in Tangerang City in 2024 are presented in Table 1. Based on Table 1, out of 104 DAM assessed in 2024, 72.1% met the sanitary hygiene requirements.

Table 1. Frequency Distribution of Sanitary Hygiene of DAM

Hygiene Sanitation	Frequency	Percentage (%)
Qualified (Value ≥80.00)	75	72.1
Did Not Qualify (Value <80.00)	29	27.9

The microbiological parameters of *E.coli* and coliforms are key indicators for determining safe drinking water (12,23). Coliform bacteria can be used as an indicator of organisms sourced from feces from both animals and humans (24). Total coliform bacteria are divided into 2 types, namely fecal (e.g., *E. coli*) and non-fecal (e.g., *Aerobacter, Klebsiella*) (25). Fecal coliforms are sourced from human and animal feces and can cause digestive tract diseases such as diarrhea (26). Meanwhile, non-fecal coliforms usually come from dead plants/animals and can cause respiratory diseases (25,27). *E.coli* and coliforms are used as standards for assessing drinking water quality in microbiological parameters and indicate the presence of pathogenic contamination that causes gastroenteritis (10). The results of the univariate analysis of the microbiological quality of *E.coli* and coliforms in 104 drinking water depots in Tangerang City in 2024 are presented in Table 2. As shown in Table 2, out of 104 samples, 28.8% tested positive for *E.coli* and 63.5% tested positive for total coliforms. Similar results were found in previous research (28), where 77.1% of AMIU samples were found to be contaminated with *E.coli* and coliforms. In a study (29), 56.25% of DAM were also found with *E.coli* contaminants. The microbiological contamination in AMIU may be linked to hygiene practices of DAM handlers during water processing (28-29). In addition, other factors such as raw water quality and sanitary hygiene of premises and equipment can also be a source of contamination in AMIU (28,30). The results of the analysis in this study showed that more than 50% of AMIU in Tangerang City in 2024 were microbiologically contaminated.

Table 2. Frequency Distribution of Microbiological Quality of Refill Drinking Water

Variable	Frequency	Percentage (%)
E.coli		
Negative (0 CFU/100 ml)	74	71.2
Positive (>0 CFU/100 ml)	30	28.8
Total *Coliform*		
Negative (0 CFU/100 ml)	38	36.5
Positive (>0 CFU/100 ml)	66	63.5

Statistical tests to find the relationship between the sanitary hygiene of DAM and the microbiological quality of drinking water were carried out using the Chi-square test. The correlation analysis results of DAM sanitary hygiene with the microbiological quality of *E.coli* and coliforms are presented in Table 3 and 4. Table 3 demonstrates that a *p*-value of 0.000 ($p<0.05$) was obtained, suggesting a significant correlation between DAM sanitary hygiene and the microbiological quality of *E.coli* in drinking water. The value of prevalence ratio (PR)=6.756 with confidence interval (CI)=95% (2.612-17.480) indicates that DAM that do not meet sanitary hygiene requirements have a 6.756 times greater risk of producing drinking water contaminated with *E.coli* than those that meet sanitary hygiene requirements. Prior studies (13,31) showed there was a relationship between the sanitation of a place and the hygiene of the handlers with the presence of *E.coli* bacteria. However, this was contrary to the results of other studies (32-33), which showed there was no association between handlers' hygiene and *E.coli* bacteria.

Table 3. Correlation Analysis of Hygiene Sanitation with E.coli Quality

Variable	*Escherichia coli*				Total		P-Value	PR (95% CI)
	Positive		Negative					
	n	%	n	%	n	%		
Hygiene Sanitation								
Did Not Qualify	17	58.6	12	41.4	29	100	0.000	6.756
Qualified	13	17.3	62	82.7	75	100		(2.612-17.480)

Table 4. Correlation Analysis of Hygiene Sanitation with total Coliform Quality

Variable	Total *Coliform*				Total		P-Value	PR (95% CI)
	Positive		Negative					
	n	%	n	%	n	%		
Hygiene Sanitation								
Did Not Qualify	24	82.8	5	17.2	29	100	0.011	3.771
Qualified	42	56	33	44	75	100		(1.299-10.951)

The results in Table 4 shows that a *p*-value of 0.011 ($p<0.05$) was obtained. This indicates a significant association between DAM sanitary hygiene and the microbiological quality of coliforms in drinking water. The PR value of 3.771 with 95% CI (1.299-10.951) indicates that DAM that do not meet sanitary hygiene requirements have a 3.771 times greater risk of producing coliform-contaminated drinking water compared to those that meet sanitary hygiene standards. The results of another study showed that location and equipment were associated with the presence of coliform bacteria (7). However, buildings, facilities, and the hygiene of handlers had no relationship with the presence of coliforms.

To analyze whether there is an influence between the predictor variable, namely DAM sanitary hygiene (X), on the response variable, namely the microbiological quality of drinking water (Y), a statistical test was carried out using the binary logistic regression test. The results of the regression analysis of DAM sanitary hygiene with microbiological quality of water are presented in Table 5. The binary logistic regression test found a substantial influence between sanitation hygiene of DAM and microbiological quality of water with a *p*-value of 0.002 ($p<0.05$). The regression coefficient value of 0.083 indicates that every one-unit increase in the DAM sanitary hygiene score will increase the probability of water meeting microbiological quality requirements by 8.3%. Furthermore, the odds ratio (OR) value of 1.087 makes it clear that well-sanitized DAM are 1.087 times more likely to produce water that meets microbiological quality, compared to poorly sanitized ones.

Table 5. Analysis of the Effect of Sanitation Hygiene of DAM on Microbiological Quality of Water

Variable	Estimated Parameter	Standar Error	W	P-Value	OR	95 % CI
Hygiene Sanitation	0.083	0.027	9.211	0.002	1.087	1.030-1.147
Constant	-7.619	2.369	10.345	0.001	0.000	

Figure 1 displays the result of mapping with circle and triangle symbols illustrating the microbiological quality and square symbols illustrating the sanitation hygiene of water depots. The results show that DAM with sanitary hygiene and microbiological quality of meeting the requirements are mostly found in Jatiuwung, Ciledug, and Neglasari districts. Meanwhile, DAM with sanitary hygiene and microbiological quality that do not meet the requirements are mostly found in the central area of Tangerang City, namely in Batuceper, Cipondoh, and Tangerang districts. In addition, the areas with the majority of DAM contaminated with microbiological agents are Karawaci and Cipondoh districts, which are also the areas with the highest rates of diarrheal disease in city of Tangerang. For the purpose of improving the quality of the DAM in these areas, the head of the administrative areas could initiate a comparative study program to areas with better-performing DAM. They can serve as a reference for DAM in areas that have not met the health standards.

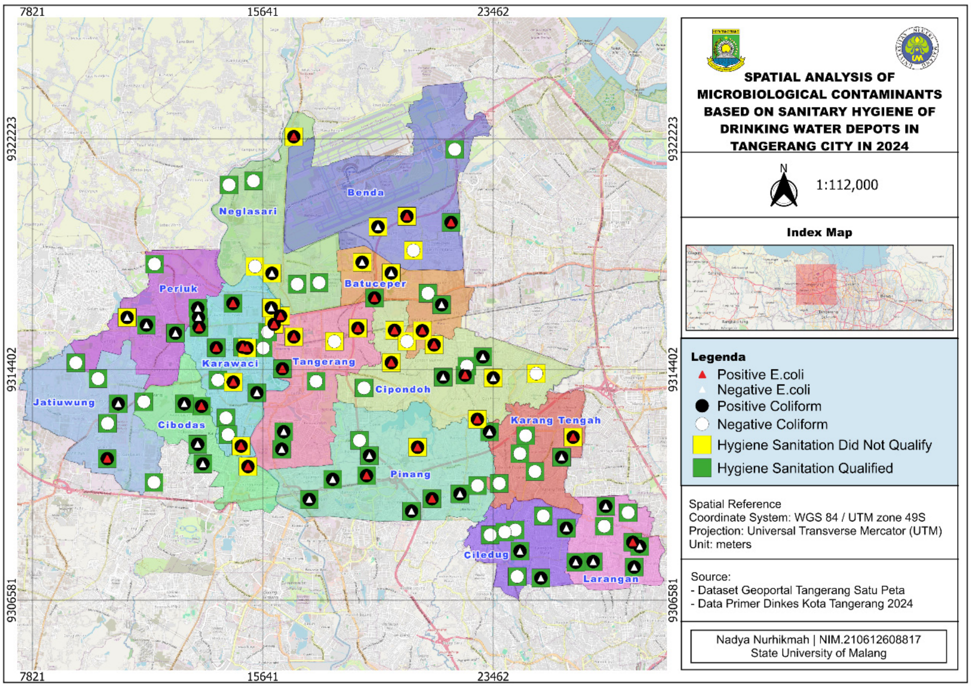

Figure 1. Spatial Analysis of Microbiological Contaminants Based on Sanitation Hygiene of DAM in Tangerang City in 2024

In addition, the mapping results showed that there were 47 DAM with contradictory correlations. Specifically, 42 DAM have qualified sanitary hygiene conditions, but their microbiological quality tested positive for contaminants. These cases were frequently found in Larangan, Pinang, and Karawaci districts. Conversely, 5 DAM had did not qualify sanitary hygiene conditions, but their microbiological quality tested negative for contaminants. The findings indicate that the sanitary hygiene condition of DAM in Tangerang City was not the only factor influencing the microbiological quality of water. Even DAM with satisfactory sanitary conditions may still produce water that does not meet the requirements. This is in line with a study in Banyumanik, which stated that there were DAM with good sanitary hygiene conditions but had unqualified water microbiological quality (28). It is possible that there are other factors outside the IKL assessment aspect of the DAM that affect the microbiological quality of drinking water. Factors such as raw water source contamination, treatment process efficacy, and environmental conditions like nearby waste disposal or fly breeding sites could play significant roles. Additionally, lapses in maintenance of treatment equipment or breaches in water distribution systems might lead to contamination despite good hygiene practices. Exploring these unmeasured variables is essential to fully understand and address the multifactorial nature of water

DISCUSSION

Unqualified sanitary hygiene scores were most often indicators of inadequate handwashing procedures at sinks, lack of sanitary hygiene training certificate for DAM handlers, absence of tightly closed trash cans, failure to conduct annual health checks on DAM handlers, and the unavailability of hand dryers at sinks. Poor DAM facilities and infrastructure, such as uncovered trash cans and unavailability of handwashing facilities and bathrooms, are assumed to result in the contamination of *E.coli* bacteria (13). This study showed that there were many DAM with sink facilities that were not equipped with dryers and handwashing instructions, as well as DAM with trash cans that were not tightly closed. Previous research stated that all DAM in the study had minimal access to sanitation facilities, and the majority of handlers did not meet personal hygiene requirements and did not have a certificate of DAM sanitation hygiene training (34-35). Uncovered trash cans were found in some DAM, which attracted flies (28), which can contaminate drinking water as they are vectors that can breed and spread bacteria. DAM sanitation hygiene training for handlers can improve knowledge and skills related to DAM sanitation hygiene that enable DAM handlers to follow the procedures, resulting in drinking water that is safe for consumption (7). DAM handlers who are not concerned with personal hygiene may cause water contamination as they have direct contact with water during the service process (28). Complimentary hygiene and sanitation training for drinking water depots is routinely organized by the Tangerang City Health Office. However, this study found that 82.7% of drinking water depots employed handlers who were not certified in hygiene and sanitation training.

Drinking water contaminated with coliforms and *E.coli* is not suitable for consumption and may can cause diseases such as diarrhea, vomiting, typhoid, dysentery, and cholera (7,18). The high contamination of coliform bacteria is often associated with the presence of other pathogens (7). *E.coli* is estimated to cause approximately 50% of gastrointestinal disorders like diarrhea (6). In this study, the laboratory test results for the highest *E.coli* bacteria reached 62 CFU/100ml, while the highest coliform bacteria reached >2420 CFU/100ml. These indicate that the drinking water fails to meet the requirements of health standards to be safely consumed, and may have a negative impact on public health if not promptly followed up with regulatory action and increased awareness among DAM owners (36).

A study conducted in Surabaya found a significant association (p-value=0.001) between the sanitary condition of DAM and microbiological quality, where 62.5% of DAM did not meet sanitation requirements, and 56.25% of the water was microbially contaminated (29). The data emphasize the importance of a holistic approach that includes regular monitoring of water quality, training of handlers, and standardization of treatment equipment to ensure the microbiological safety of drinking water. This, however, is not in line with the results of other studies (7,32) which showed no significant correlation between sanitation and hygiene of DAM handlers and the presence of *E.coli* and coliforms in drinking water. Other studies (28,37) suggested that there was no link between the sanitary hygiene conditions of DAM and the microbiological quality of drinking water. This finding was due to the better environmental conditions in the studied DAM, where all DAM had clean drainage systems, and the handlers had met the prescribed health aspects, and water treatment was carried out using equipment designed to reduce the risk of contamination (7).

Previous research found that there was an influence between the place of drinking water treatment, the completeness of sanitation facilities, and the hygiene of handlers on the presence of bacteria in drinking water (19). Sanitary facilities variables affect the microbiological quality of refilled drinking water. Factors such as the pollution-prone location of the drinking water depots, the use of unmaintained equipment, and the lack of knowledge of handlers regarding hygiene practices contribute to microbiological contamination (10,38). In addition, raw water quality is an important determinant as contaminated raw water increases the risk of contamination despite treatment processes (39).

Another study identified the risk of treatment process failure that affects the quality of AMIU in Surabaya City (40). The results showed that the main risk priorities were inadequate contact time of ultraviolet (UV) lamps, unscheduled replacement of filter cartridges, and lack of maintenance on silica sand. A similar study found that the leading causes of coliform contamination in AMIU were UV and ozonation contact time, as well as inadequate equipment replacement and disinfection maintenance. Study (13) found that ozone and UV sterilizers were not used properly or not functioning at all in many DAM. The use of UV only at the point of water bottling reduces its effectiveness in removing bacteria (34). UV and ozone lamps function as disinfectants for water that has already undergone treatment. According to Ministry of Health Regulation No. 43 of 2014 regarding Sanitary Hygiene of Drinking Water Depots, UV disinfection equipment must function properly and remain operational (41). Filters and UV light are the most important tools in DAM that serve to filter and remove germs and bacteria from drinking water (42). Factors outside of sanitary hygiene that contribute to water contamination include raw water quality, treatment process failures, and infrastructure deficiencies. Poor raw water quality increases the risk of contamination despite treatment efforts. Additionally, inadequate maintenance of treatment equipment—such as insufficient UV contact time or unscheduled filter replacements—can compromise water safety.

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to utilize the data for this study. The study might suffer from selection bias due to the reliance on secondary data from the Health Office and the quota sampling method. Additionally, the absence of detailed demographic data about the DAM operators or their operational practices introduces potential confounding factors. The authors should consider random sampling in future studies to reduce bias and include more detailed information about the operational conditions of the DAM. Furthermore, supplementing secondary data with primary interviews or surveys with operators could provide deeper insights into the observed discrepancies.

CONCLUSION

This study assessed the microbiological quality of drinking water refill station (DAM) in Tangerang City, finding that while 72.1% met hygiene standards, 63.5% still showed contamination with E. coli and coliform bacteria. Statistical analysis revealed a significant positive correlation between better sanitation scores and improved microbiological quality, with each unit increase in hygiene score raising the likelihood of compliant water by 8.3%. Spatial analysis using GIS mapped the distribution of DAM, showing that depots with good sanitation and microbiological quality clustered in districts like Jatiuwung, Ciledug, and Neglasari, whereas high contamination areas were more dispersed. The thematic maps highlighted high-risk zones, emphasizing the importance of targeted interventions. The findings demonstrate a spatial relationship where improved sanitation correlates with better water quality, and geographic distribution influences contamination risks. These insights support strategic policy-making and resource allocation to enhance water safety across different districts. Overall, integrating microbiological data with spatial analysis provides a comprehensive approach to managing drinking water quality in Tangerang City.

AUTHORS' CONTRIBUTION

NN: Conceptualization, Methodology, Software, Writing, and Editing. MVH: Conceptualization, Methodology, and Reviewing. HN: Data Curation, Conceptualization, and Reviewing.

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