THE STUDY OF SEPTIC TANK PROXIMITY ON *COLIFORM, E. COLI*, AND ORGANIC CONTAMINATION IN SHALLOW GROUNDWATER: A CASE STUDY OF DKI JAKARTA

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Abstract

Groundwater in DKI Jakarta is subject to microbiological contamination. Approximately 32% of the population in DKI Jakarta relies on groundwater as an alternative source of clean water, highlighting the urgent need to address and prevent contamination. This study aims to investigate the effect of the separation distance between septic tanks and wells on the levels of *Total coliform* (TC), *Escherichia coli* (EC), and organic parameter contamination in shallow groundwater. Groundwater quality data, including TC, EC, and organic parameters from 265 monitoring points in DKI Jakarta, was obtained from the Jakarta Environment Agency in 2022. A quantitative descriptive approach, incorporating spatial mapping of bacterial and organic contamination using Geographic Information System (GIS) tools, was employed. MANOVA analysis using SPSS 26 was conducted to determine the relationship between septic tank distances and shallow water contamination levels. Results indicate that the separation distance between septic tanks and wells significantly influences TC and EC contamination in Jakarta Pusat, Jakarta Timur, and Jakarta Barat. Organic contamination, however, is significantly affected only in Jakarta Pusat and Jakarta Timur. In contrast, Jakarta Utara was identified as the most contaminated region, with 84% of groundwater samples showing TC contamination, 55% exhibiting Escherichia coli (EC) contamination, and 69% affected by organic pollution. However, these contaminations were not proven to be influenced by the proximity of septic tanks. This is likely due to the area's coastal location, where hydrogeological conditions and diverse pollution sources play a more significant role in groundwater contamination. Improvements in sanitation infrastructure could significantly enhance groundwater quality, particularly in highly vulnerable areas such as Jakarta Utara.

Keywords: *Shallow groundwater, Total coliform, Escherechia coli, Septic tank, Geographic Information System (GIS)*

Introduction

Anthropogenic activities, such as improper waste disposal, farming practices, rainwater infiltration, and the degradation of natural land surfaces, significantly contribute to groundwater contamination (Reay, 2004). Groundwater quality is further compromised by rapid industrialization, which drives lifestyle changes and environmental challenges, including water pollution.

The use of well water poses a health risk from groundwater contamination due to anthropogenic activities. Coliform bacteria, commonly found in the digestive tract of humans and animals, serve as a key parameter for assessing the quality of drinking water and its suitability for household purposes. *Escherichia coli* (EC), a specific indicator of fecal contamination, is widely used to monitor water quality in accordance with World Health

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Organization (WHO) standards. The detection of E. coli in groundwater is sufficient evidence to deem the water unsafe for drinking unless properly treated (Olalemi et al., 2021). The study quantitatively assessed the microbial quality of groundwater sources, revealing that persistent fecal contamination poses a significant risk for gastrointestinal infections. Consequently, it is crucial to analyze the presence of *Total Coliforms* (TC) and *Escherichia coli* (EC) in well water to evaluate groundwater quality and safeguard public health.

DKI Jakarta, as the country's capital, is experiencing fairly rapid population growth and modernisation. The total population of DKI Jakarta is 10,672,100, with its density being 16,165 people/km² in 2023. Varying population density is distributed in five administrative regions namely Jakarta Utara, Jakarta Pusat, Jakarta Timur, Jakarta Selatan dan Jakarta Barat. The majority (79.39%) of household drinking water sources is bottled water, followed by ground water (12.57%), piped water (7.64%) and protected wells (0.69%).

In general, the Jakarta aquifer is divided into three (3) layers (Samsuhadi, 2018). The first layer is an unconfined, shallow groundwater aquifer, extending up to 50 meters below the ground surface. The second layer lies at depths between 50 and 150 meters below the surface. The third layer, a confined aquifer located between 150 and 250 meters below the ground surface, is a compressed aquifer also referred to as an artesian aquifer.

Studies have shown that, groundwater near septic tanks often contains high levels of these pathogens, making the water unsafe for drinking (Bouderbala, 2019; Ferrer et al., 2020; Sekgobela et al., 2024). Septic tanks can be a source of various pathogens, including *Escherichia coli (EC), fecal coliforms*, and other enteric bacteria, which can cause diseases such as gastroenteritis, hepatitis, and cholera (Bouderbala, 2019; Sekgobela et al., 2024; Yates, 2011).

This study aims to investigate the effect of the separation distance between septic tanks and wells on the levels of TC, EC, and organic parameter contamination in shallow groundwater within the DKI Jakarta area. MANOVA is employed as a statistical method to compare means of multiple dependent variables across groups. It is particularly valuable for analyzing relationships between parameters like TC, EC, and organic contamination, with the distance between septic tanks and wells as the independent variable. This approach aids in identifying contamination sources and supporting targeted interventions to improve septic tank and well management systems..

Additionally, this study maps groundwater pollution patterns to identify high-risk areas for the spread of waterborne diseases due to groundwater contamination. The findings are expected to contribute to Sustainable Development Goal (SDG) 6 by promoting strategies to ensure universal access to clean water and safe sanitation.

Research Methodology

1. Groundwater samples were collected from 267 locations across the DKI Jakarta area, based on data from groundwater quality monitoring conducted by the Environment Agency in 2022. The separating distance between each well and its nearest septic tank data were included. (Bidang Pengendalian Dampak Lingkungan & Jakarta, 2022).
2. The ground water quality data that used in this research are organic parameters, including permanganate value ($KMnO_4$), *Total Coliform* (TC), and *Escherichia coli* (EC) concentrations
3. Statistical analysis:
   a. Initial steps in the statistical analysis were carried out to ensure that the data was free from input errors and to identify and handle extreme data that could possibly affect it. These included preliminary data examination, which consists of data validation, and outlier detection, to explore all the data, descriptive statistical analysis and data visualisation, in order to understand the data distribution and the initial relationship between variables. Furthermore, the statistical assumptions of

normality, homogeneity of variants in the treatment and control groups were tested with the Levene statistical test and the data independence test.

b. The multivariate significance difference test between 3 parameters, namely organic, TC and EC, on the distance between the septic tank and the well was simultaneously carried out by the Multivariate Analysis of Variance (MANOVA) Method.
   - Null Hypothesis (H_0): There is no significant difference in the mean concentrations of the parameters (Organic Permanganate, *Total Coliform* [TC], and *Escherichia coli* [EC]) across varying distances between septic tanks and wells, and
   - Hypothesis (H_1): At least one parameter's mean differs significantly, the significant level (alpha level)=0,5.

4. The spatial mapping of groundwater quality, including organic parameters, Total Coliform (TC), and Escherichia coli (EC), is presented in thematic maps using GIS. These maps visualize the concentrations of organic matter, TC, and EC using color scales to represent contamination levels in relation to groundwater quality standards, as defined by the Regulation of the Minister of Health Number 2 of 2023 (Ministry of Health, 2023) The data are categorized based on well depth (H < 50 meters for shallow groundwater and H ⩾ 50 meters) and the minimum distance criteria between septic tanks and wells (JS ⩽ 10 meters and JS > 10 meters).
5. The data grouping to visualise the concentration of organic matter, TC, and EC by category.
6. Parameter organic substance (mg/liter $KMnO_4$) in accordance with the environmental health quality standard for organic matter, media =10mg/liter, with the following compositions:
   - CT ≤ 0.1 mg/litre
   - C > 0.1 dan C ≤10 mg/litre
   - C >10 mg/litre

   TC and EC parameters with maximum standard = 0 CFU/100ml :
   - CT ≤ 0 CFU/100ml,
   - C > 0 and C≤1,000 CFU/100ml,
   - C >1,000 and C≤10,000 CFU/100ml,
   - C>10,000 CFU/100ml

Wells with a depth of less than 50 meters and located within 10 meters of septic tanks present a high risk of contaminants entering the groundwater. Particular attention should be given to these conditions when parameter concentrations exceed the quality standards, specifically Organic Permanganate > 10 mg/L, and TC and EC concentrations > 0 CFU/100 mL.

Additionally, shallow groundwater located more than 10 meters from septic tanks but still showing TC and EC concentrations > 0 CFU/100 mL or Organic Permanganate > 10 mg/L requires further investigation. A more in-depth analysis is necessary to identify other potential sources of pollution affecting these areas.

Results and Discussion

Based on a total of 267 groundwater quality data validations, there are two (2) data that did not fulfill the requirements. They were suspected as data input errors. Therefore, this study used 265 legitimate data.

Table 1. Descriptive Analysis

Parameter	Unit	N	Standard*	Minimum	Maximum	Mean	Std. Dev
The distance between the septic tank and the well	m	265	-	2.0	50	13.5	8.2
Well Depth	m	265	-	2.0	80	22.5	11. 6
Total coliform (TC)	CFU/100 ml	265	0	0.0	31,000,000	184,215.0	1,958,185.5
Escherichia coli (EC)	CFU/100 ml	265	0	0.0	10,000,000	52,300.4	624,660.2
Total Organik ($KmnO_4$)	mg/liter	265	10	2.0	29.7	4.2	4.2

*) Regulation of the Minister of Health, Indonesia, No 2 of 2023

Based on the descriptive analysis, the TC concentration in groundwater showed significant variations in each parameter across sampling points, with a minimum value 0 CFU/100 mL to a maximum 31,000,000 CFU/100 mL. The average value is 184,215.0 CFU/100 mL ±1,958,185.5 CFU/100. Meanwhile, EC concentrations showed extreme variations from 0 to 10,000,000 CFU/100 mL, with an average of 52,300.34 CFU/100 mL and a standard deviation of 624,660.2 CFU/100 mL. The organic permanganate concentrations showed a minimum of 2.03 mg/L and a maximum of 29.7 mg/L. Although the maximum value of organic permanganate content exceeds the quality standard (>10mg/liter), the average organic concentration in groundwater is still considered to be a quality standard of 4.2 ± 4.2 mg/litre.

The distance of the sampling point to the septic tank ranged from 2 to 50 meters, with an average of about 47.05 meters and a standard deviation of 13.5 meters. The depth of the well also varies significantly, from a minimum of 2 meters to a maximum of 80 meters. With an average groundwater depth of 22.5 meters and a standard deviation of 12.6 meters, this illustrates that the groundwater depth is significantly less than 50 meters. Thus, this study only focused on shallow groundwater samples, using 256 sampling location data from the 265 existing data.

Table 2. Results of MANOVA Test between 3 Organic, TC, EC, and the Distance of the Septic Tank

Source		df	df Total	Mean Square	F	Sig.	R^2	Ajusted R^2
Septic tank distance (DKI Jakarta)	Organic $KMnO_4$	54	256	20.9	1.220	0.165	0.274	0.045
	Total Coliform			2,016,138,757,234	0.447	1.000	0.107	-0.133
	E.Coli			183,291,875,257	0.394	1.000	0.096	-0.147
Septic tank distance (Jakarta Pusat)	*)Organic $KMnO_4$	22	44	14.2	3.920	***0.001***	***0.804***	***0.599***
	*)Total Coliform			81,914,431	13.726	***0.000***	***0.935***	***0.867***
	*)E.Coli			14,421,901	14.993	***0.000***	***0.940***	***0.877***
Septic tank distance (Jakarta Utara)	Organic $KMnO_4$	13	30	41.5	0.949	0.532	0.435	-0.240
	Total Coliform			28,040,486,473.872	0.771	0.678	0.385	-0.114
	E.Coli			2,801,154,606,705	0.730	0.713	0.372	-0.138
Septic tank distance (Jakarta Timur)	*)Organic $KMnO_4$	29	68	10.1	2.565	***0.003***	***0.662***	***0.404***
	*)Total Coliform			369,629,609,616	6247.447	***0.000***	***1.000***	***1.000***
	*)E.Coli			513,911	4.304	***0.000***	***0.767***	***0.589***
Septic tank distance (Jakarta Barat)	Organic $KMnO_4$	23	54	37.0	1.600	0.113	0.551	0.207
	*)Total Coliform			219,886,168	19.690	***0.000***	***0.938***	***0.890***
	*)E.Coli			97,397,540	80.322	***0.000***	***0.984***	***0.972***
Septic tank distance (Jakarta Selatan)	Organic $KMnO_4$	21	60	0.7	0.203	1.000	0.101	-0.396
	Total Coliform			11,734,056	0.499	0.954	0.216	-0.217
	E.Coli			50,079	0.601	0.892	0.249	-0.166

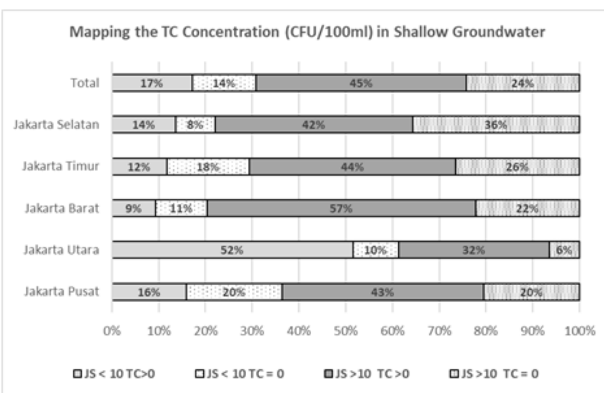
Based on the results of the statistical test using Multivariate Analysis of Variance (MANOVA), there is a significant difference in the average concentration value of the organic, TC and EC parameter to various distances between septic tank distances to wells in Jakarta Pusat and Jakarta Timur. Meanwhile, only the average concentrations of 2 variables, namely TC and EC parameters, are significantly different, due to the difference in septic tank distances to wells in Jakarta Barat. This indicates that, the proximity of the septic tank to the well has a significant influence on the TC and EC variables in groundwater quality in Jakarta Barat.

Total Coliform (TC)

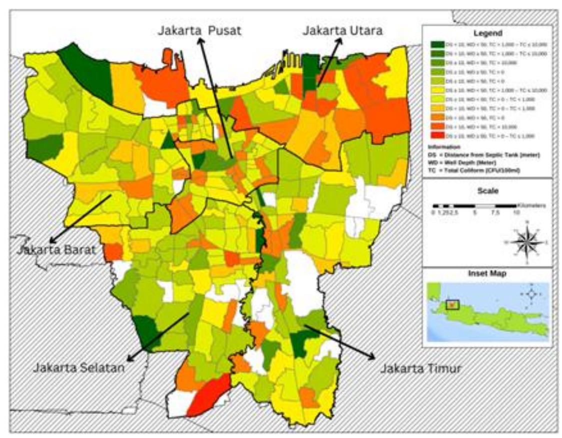
Total coliform is a group of bacteria that is often used as an indicator of water quality, because its presence can indicate the possibility of contamination by pathogenic bacteria. The distribution of TC shows significant value variation in the administrative area of DKI Jakarta as a whole, but it has not been proven that the variation is influenced by the distance between the septic tank and the well (Table 2). Figure 3 shows the concentration of total coliform (TC CFU/100 ml) in shallow groundwater throughout the DKI Jakarta area.The chart shows the total coliform (TC) concentration (in CFU/100 ml) in shallow groundwater across different areas in Jakarta. The categories in the bars represent four conditions based on the distance between septic tanks and wells and TC levels. The graph explains four conditions based on the distance of the septic tank with the groundwater sampling location based on the TC content in the groundwater according to the quality standard, namely TC=0 and exceeding the TC>0 CFU/100ml quality standard (Minister of Health Regulation No. 2 of 2023). Most of the groundwater samples were contaminated with total coliform (TC) (TC > 0 CFU/100 ml).

This is reinforced by the results of graphical and spatial mapping using GIS (Figure 1), showing that the total concentration of coliform that exceeds the quality standard with a septic tank distance of less than 10 meters only occurs in 17% of the sample locations, while 45% occurs in the location of water source samples that are more than 10 meters away from the septic tank throughout the DKI Jakarta area. The remaining 38% of locations still have TC concentration values that meet quality standards, namely TC = 0 CFU/100 ml.

The percentage of sample point locations that were not contaminated by TC (TC = 0 CFU/100ml) was relatively lower than that of contaminated groundwater sample locations in all areas in DKI Jakarta. Jakarta Selatan and Jakarta Timur have a slightly higher proportion of uncontaminated areas (TC = 0) which are 44% and 42%, respectively. This is followed by the other 3 regions, namely Jakarta Pusat (40%), Jakarta Barat (33%) and Jakarta Utara (16%).



a. Distribution of TC contamination in shallow groundwater



b. Mapping the concentration of TC in shallow groundwater

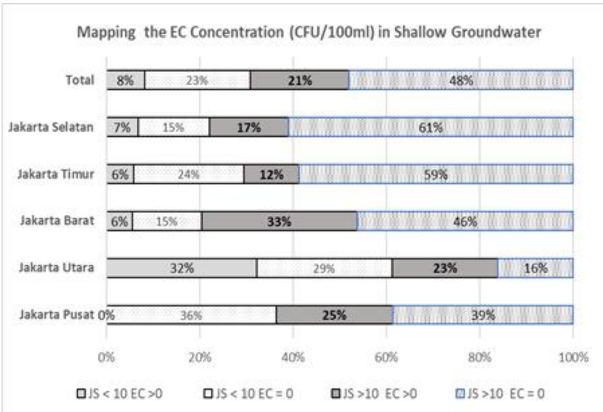
Figure 1. Mapping the concentration of *Total Coliform* (TC) in shallow groundwater in DKI Jakarta by region

Eschericia coli (EC)

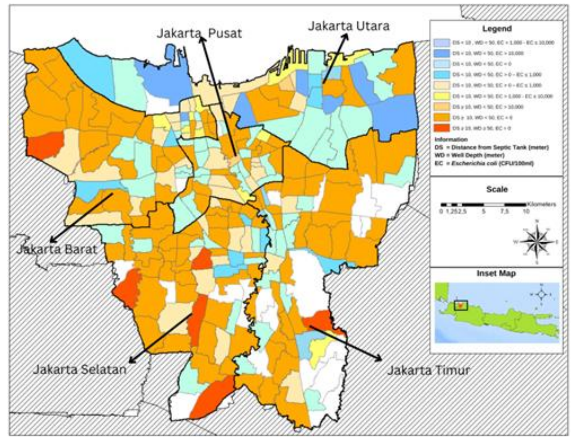
EC is a bacterium found in the digestive tract of humans and warm-blooded animals. The presence of EC in groundwater indicates fecal contamination, which can come from a poor sanitation system. Based on the results of the analysis, the concentration of E.coli at several monitoring points also exceeded the set quality standards, which were more than 0 CFU/100ml. The percentage of sample point locations that were contaminated by EC can be seen in Figure 2. There was 29% location in DKI Jakarta, 24% in Jakarta Selatan and 18% in Jakarta Timur, 25% in Jakarta Pusat, 35% in Jakarta Barat and 55% in the Jakarta Utara.

The uncontaminated areas (EC = 0), have a slightly higher proportion. There was 71% location in DKI

Jakarta, 76% in Jakarta Selatan and 82% in Jakarta Timur while the other 3 regions are Jakarta Pusat (75%), Jakarta Barat (61%) and Jakarta Utara (45%) as shown in Figure.



a. Distribution of EC contamination in shallow groundwater

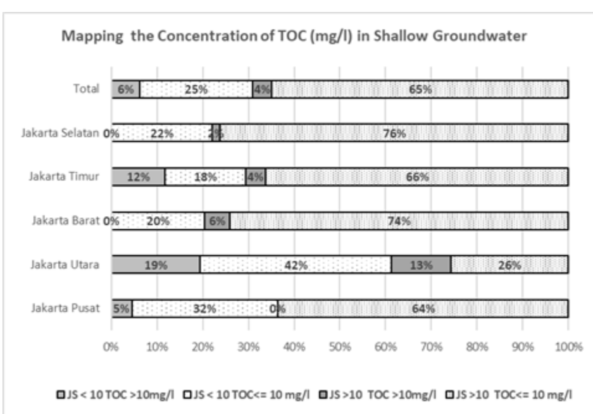


b. Mapping the concentration of EC in shallow groundwater

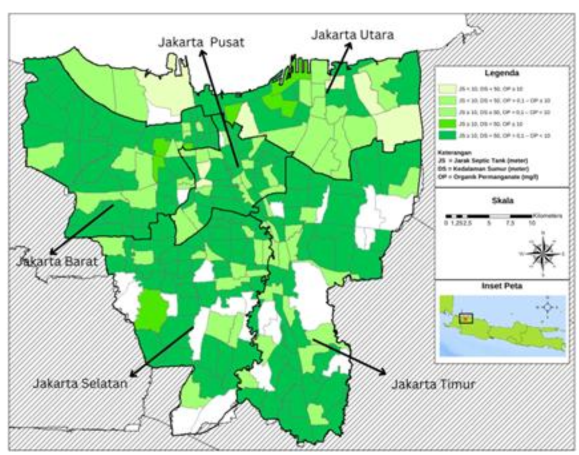
Figure 2. Mapping the concentration of *Escherecia coli* (EC) in shallow groundwater in DKI Jakarta by region

Organic Permanganate

The concentration of organic at several monitoring points also exceeded the set quality standards, which were more than 10mg/litre. The percentage of sample point locations that were contaminated by total organic can be seen in Figure 3. There was 10% location in DKI Jakarta, 4% in Jakarta Selatan and 16% in Jakarta Timur, while the other 3 regions were 5% in Jakarta Pusat, 6% in Jakarta Barat and 31% in the Jakarta Utara. The uncontaminated areas have a slightly higher proportion. There was 90% location in DKI Jakarta, 96% in Jakarta Selatan and 84% in Jakarta Timur, while the other 3 regions are in Jakarta Pusat (95%), in Jakarta Barat (94%) and in Jakarta Utara (69%) (Figure 3). Organic matter, particularly dissolved organic carbon (DOC), can enhance the transport of EC by occupying attachment sites in soil and aquifer materials, preventing pathogen attachment and leading to faster and longer-distance transport. This effect is more pronounced with higher concentrations of DOC, which can significantly reduce EC attachment to soil particles (Weaver et al., 2013).



a. Distribution of organic contamination in shallow groundwater



b. Mapping the concentration of organic in shallow groundwater

Figure 3. Mapping the concentration of organic parameter in shallow groundwater in DKI Jakarta by region

Based on the results of the MANOVA analysis (Table 2), it was found that in Jakarta Pusat and Jakarta Timur, there is a significant difference in the concentrations of *Total Coliform* (TC), *Escherichia coli* (EC), and organic contaminants, influenced by the distance between septic tanks and wells. These findings indicate that the proximity of septic tanks significantly affects TC concentrations. In Jakarta Pusat, 58% of the monitored locations are contaminated with TC, with 16% being attributed to proximity to septic tanks and 43% to other factors. In Jakarta Timur, 56% of the locations are contaminated with TC, 12% due to proximity to septic tanks and 44% attributed to other factors (Figure 1). For EC pollution, only 6% of the locations near septic tanks in Jakarta Timur are affected, while no such contamination occurs near septic tanks in Jakarta Pusat. However, EC contamination was observed at a distance greater than 10 meters from septic tanks in 25% of locations in Jakarta Pusat and in 12% of locations in Jakarta Timur (Figure 2). Organic contamination in wells < 10m away occurs as much as 12% in Jakarta Timur and 5% in Jakarta Pusat, while organic contamination with a distance of septic tank more than 10m does not occur in Jakarta Pusat, but there is a low persentage of 4% in Jakarta Timur (Figure 3).

In Jakarta Barat, 66% of groundwater samples were contaminated with Total Coliform (TC), with evidence indicating that the distance between septic tanks and wells significantly affected TC and Escherichia coli (EC) concentrations. Specifically, 57% of contamination occurred in areas where septic tanks were more than 10 meters from wells, while 9% occurred in areas where the distance was less than 10 meters, with a mean square value for TC concentration of approximately 220 million (Figure 1). EC contamination was also notable, affecting 39% of locations. Of these, 6% occurred in areas where septic tanks were less than 10 meters from wells, and 36% in areas where the distance exceeded 10 meters (Figure 2). In contrast, organic contamination was not influenced by the distance between septic tanks and wells. Organic pollution was observed in only 6% of locations where wells were more than 10 meters from septic tanks (Figure 3).

In two regions, Jakarta Utara and Jakarta Selatan, the results of the MANOVA analysis (table 2) indicated that the distance between septic tanks and wells did not have a significant effect on *Total Coliform* (TC), *Escherichia coli* (EC), or organic contaminant concentrations in groundwater.Jakarta Utara exhibited greater variability in pollutant concentrations, with some monitoring points showing very high levels of TC and EC. GIS mapping revealed that monitoring points with high contamination levels were primarily located near industrial areas and regions with high population density. In this region, 84% of shallow groundwater samples were contaminated with TC. Of these, 52% occurred at locations where the distance between septic tanks and wells was less than 10 meters, and 32% occurred at locations where the wells were more than 10 meters away from septic tanks. As a coastal area, contamination in Jakarta Utara is likely influenced by hydrogeological conditions. Factors such as soil permeability and water table depth play a critical role in the movement of contaminants, as highly permeable soils and shallow water tables increase the risk of pathogen transport to groundwater (Stall, C., et al, 2014; Bouderbala, 2019; Mester et al., 2023).

In Jakarta Selatan, 53% of groundwater samples exceeded the quality standard for TC concentrations. Of these, 14% were from areas where septic tanks were less than 10 meters from wells, while 42% were from areas where wells were more than 10 meters from septic tanks (Figure 1). The population density in Jakarta Selatan is relatively low compared to that in other regions. Contamination in this area is often attributed to inadequate construction or maintenance of wells, which may cause pollutants to infiltrate groundwater (Kairunnisa et al., 2021; Naily et al., 2023). Additionally, flooding events may introduce pathogens from surface water into groundwater systems (Mapili, K., et al, 2022). Therefore, further research is needed to identify other sources of pollution contributing to groundwater contamination in Jakarta Selatan.

This suggests that, the proximity to septic tanks is a critical factor towards the extent of EC contamination in surrounding environments. The presence and transport of EC in environments near septic tanks are significantly influenced by the proximity to the tanks and the presence of organic matter. Septic tanks can be a source of EC contamination, and organic matter can enhance the transport and growth of EC, posing environmental and public health risks. Effective management and monitoring of septic systems are crucial to mitigate these risks. Properly maintained septic systems can significantly reduce the likelihood of pathogenic contamination, while poorly maintained systems pose a substantial risk to groundwater quality and public health. Septic tank maintenance plays a crucial role in mitigating the risk of groundwater contamination by pathogens.

Conclusions

The results show that, the distance of the septic tank has a significant influence on the level of TC and EC groundwater contamination in the areas of Jakarta Pusat, Jakarta Timur, and Jakarta Barat, while organic contamination is affected by septic tanks in Jakarta Pusat and Jakarta Timur. Jakarta Utara is the most contaminated area, with 84% of groundwater monitoring sample locations being contaminated with TC, 55% contaminated with EC, and 69% contaminated with organic from various non-specific sources of pollutants. EC contamination in groundwater has significant environmental and public health implications. Monitoring groundwater quality for EC contamination is essential, and preventive measures are needed to minimise the spread of EC in groundwater.

In conclusion, while MANOVA might have shown no significant variations in pathogen concentrations between specific locations, groundwater contamination can still occur due to a combination of environmental, hydrological, and human factors. To reduce the risk of pollution, it is necessary to make efforts to improve sanitation systems, to implement strict supervision of domestic and industrial waste management, and to educate the public about the importance of maintaining groundwater quality. Understanding these factors is crucial for effective groundwater management and contamination prevention. Further research and the development of effective water-quality management strategies are crucial to mitigate the health risks associated with groundwater contamination.

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