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Groundwater Quality Assessment and Potential Public Health Risks in Rural Agricultural Areas of Indonesia: A Physicochemical and Microbiological Approach

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ABSTRACT

Groundwater is a critical water source for rural communities, particularly in areas where centralized water-supply systems are limited or absent. Despite its essential role, groundwater quality in agricultural regions of Indonesia remains insufficiently monitored, creating a significant gap in public health surveillance and environmental management. Previous studies have assessed groundwater quality in urban or peri-urban contexts; however, integrated physicochemical, microbiological, and spatial assessments in rural agricultural settings of West Java Province remain scarce. This study aimed to assess the physicochemical and microbiological quality of groundwater in a rural agricultural area in Indramayu District, West Java Province, Indonesia, and to identify potential contamination risks associated with land use and local environmental conditions. A total of 30 household well samples were collected and analyzed for pH, temperature, total dissolved solids (TDS), electrical conductivity, dissolved oxygen, salinity, nitrate, phosphate, iron, manganese, and total coliform. Spatial distribution of contamination risk was assessed through ArcGIS-based distribution mapping. The results showed that most basic physicochemical parameters were generally within acceptable ranges. Nevertheless, several wells showed elevated TDS, nitrate, iron, and total coliform levels. Nitrate concentrations ranged from 2.40 to 62.50 mg/L, with sampling points S8, S9, S10, and S18 exceeding the WHO guideline value of 50 mg/L. Microbiological contamination was a major concern, as only 8 of 30 samples (26.67%) met the safety requirement of 0 MPN/100 mL for total coliform. Spatial analysis indicated that high-risk wells were concentrated near agricultural land, residential settlements, and drainage channels, reflecting the combined influence of fertilizer application, septic tank leakage, domestic wastewater, and surface runoff infiltration. These findings confirm that rural groundwater quality in Indramayu District is compromised by both agricultural and domestic pollution sources, with direct implications for waterborne disease risk and long-term public health. Integrated monitoring, improved well construction standards, adequate septic tank setback distances, sanitation system improvements, and community-level water treatment are urgently recommended.

***Keywords**:* groundwater quality; nitrate contamination; total coliform; rural agriculture; public health risk; Indonesia

INTRODUCTION

Groundwater is one of the most essential freshwater resources for domestic consumption, agricultural activities, and rural livelihoods (Van Tuan et al., 2024). In many rural and peri-urban areas, groundwater is often used as the main source of drinking water because it is relatively accessible, available throughout the year, and less dependent on centralized water-supply infrastructure (Foster et al., 2020). However, groundwater quality is not always safe for direct consumption, as it may be affected by both natural geochemical processes and anthropogenic pollution. Recent studies have emphasized that groundwater deterioration caused by geogenic and human-induced contaminants has become a major challenge for safe water supply, public health protection, and sustainable environmental management (Xie et al., 2023; Wang et al., 2023)

The quality of groundwater is influenced by various physical, chemical, biological, geological, and land-use factors. Naturally, groundwater may contain dissolved minerals originating from soil and rock formations (Egbueri, 2019a). Nevertheless, human activities such as intensive agriculture, fertilizer application, livestock waste, domestic wastewater discharge, and poorly managed sanitation systems can significantly increase the risk of contamination. In agricultural and settlement areas, nitrate pollution is one of the most common groundwater-quality problems. A systematic review by (Verma et al., 2023) reported that land use is a determining factor for nitrate contamination, where fertilizers and manure are dominant sources in agricultural areas, while septic tank leakage and open drainage systems are major contributors in residential areas.

Nitrate contamination in drinking water has important implications for public health. High nitrate levels in groundwater may pose risks to vulnerable populations, In addition, long-term exposure to contaminated groundwater may contribute to broader health concerns, especially when communities rely on untreated well water for daily consumption. The World Health Organization emphasizes that drinking-water quality management should be based on health protection, risk assessment, hazard identification, and continuous surveillance from catchment to consumer (chronicle & 2011, 2008; WHO, 2022) Therefore, groundwater monitoring is essential not only for environmental evaluation but also for preventive public health management.

In addition to chemical contamination, microbiological pollution is a critical indicator of groundwater safety. The presence of total coliform or fecal coliform in groundwater indicates possible contamination from human or animal waste. A systematic review of onsite sanitation systems confirmed that these facilities act as a significant source-pathway for the transmission of E. coli, nitrate, and total coliform into adjacent groundwater, particularly when wells are located within inadequate setback distances from sanitation infrastructure (Mbae et al., 2024) This condition is commonly found in areas where wells are located close to septic tanks, drainage channels, animal cages, or poorly protected sanitation facilities. In the Indonesian context, coliform contamination of shallow groundwater has been shown to be strongly associated with well construction type, distance from pollution sources.Microbial contamination is particularly concerning because it can directly cause waterborne diseases when contaminated water is consumed without treatment. (chronicle & 2011, 2008) states that microbiological safety remains a fundamental requirement in drinking-water quality because pathogenic contamination can lead to acute health impacts in exposed populations.

Groundwater contamination in rural agricultural areas is often intensified by poor well construction, shallow aquifer conditions, inadequate sanitation infrastructure, and limited community awareness regarding safe water management (Priyan, 2021b, 2021a; Yang et al., 2025). Wells that are uncovered, located below ground level, or positioned near pollution sources are more vulnerable to infiltration by surface runoff and domestic wastewater. Previous studies have also shown that septic systems and agricultural activities can strongly influence groundwater quality, particularly in areas without adequate sewerage systems and regular water-quality monitoring (Verma et al., 2023) (Herawati et al., 2024)

In Indonesia, many rural communities continue to depend on groundwater from dug wells or shallow bore wells for drinking, cooking, bathing, and washing. Studies on groundwater self-supply in Indonesian cities found that E. coli was detected in the majority of dug-well sources, with unprotected wells significantly more likely to be contaminated than boreholes, and proximity to sanitation systems within 10 m identified as a major risk factor (Genter et al., 2022)

However, routine groundwater-quality monitoring is still limited in several rural areas. As a result, local residents may use groundwater without knowing whether it meets drinking-water quality standards. This situation increases the possibility of long-term exposure to nitrate, dissolved solids, metals, and microbial contaminants. Groundwater-quality assessment is therefore necessary to support local environmental management, public health protection, and sustainable water-resource planning.

Several parameters are commonly used to assess groundwater quality, including pH, temperature, total dissolved solids, electrical conductivity, salinity, dissolved oxygen, nitrate, phosphate, iron, manganese, and microbiological indicators (Egbueri, 2019b). Elevated concentrations of iron and manganese in groundwater are frequently of geogenic origin, originating from the natural dissolution of aquifer sediment minerals under reducing conditions, though anthropogenic inputs from organic-rich wastewater can further promote their mobilization (Islam & Mostafa, 2023; (Podgorski et al., 2022) These parameters provide important information regarding the chemical condition, pollution level, and potential usability of groundwater for domestic purposes.(Wang et al., 2023) argued that linking groundwater quality with health outcomes is important to make groundwater-related risks more visible, especially because groundwater contamination often occurs gradually and is not easily detected without laboratory testing.

Based on these considerations, this study aims to assess the physicochemical and microbiological quality of groundwater in a rural agricultural area in Indramayu District, West Java Province, Indonesia and to evaluate its potential implications for public health. Specifically, this research seeks to determine whether groundwater quality meets drinking-water quality standards, identify potential contamination sources, and provide recommendations for community-based groundwater protection. The novelty of this study lies in its simultaneous and integrated assessment of physicochemical and microbiological groundwater quality parameters within the specific rural agricultural context of Indramayu District, West Java — a region characterized by intensive paddy and vegetable farming, high dependence on household dug wells, and limited routine groundwater monitoring. Unlike previous studies that typically address chemical or biological quality in isolation or in more urbanized settings, the present study applies a spatial distribution approach using ArcGIS-based mapping to identify contamination risk patterns across 30 sampling points representing diverse land-use and sanitation conditions. The expected findings are that groundwater in the study area will exhibit elevated nitrate in agriculturally influenced wells and elevated total coliform in residentially influenced wells, with spatial clustering of high-risk points near anthropogenic pollution sources.

The findings of this study are expected to provide several important scientific and practical benefits. From a scientific perspective, the study contributes empirical data on groundwater quality in an understudied rural district of West Java, adding to the growing body of evidence linking agricultural land use and poor sanitation infrastructure to groundwater contamination in developing countries. From a public health perspective, the identification of high-risk wells and contamination hotspots can directly inform targeted health surveillance and community-based intervention programs. From a policy perspective, the results can support local government efforts in developing evidence-based groundwater protection regulations, improving well construction standards, and prioritizing sanitation infrastructure investments in vulnerable rural communities. The research also reinforces the national agenda under the Indonesian Ministry of Health Regulation (Permenkes No. 2 Tahun 2023) on drinking water quality

standards, which mandates that groundwater used for domestic purposes must comply with stipulated physicochemical and microbiological thresholds. By providing spatially explicit risk data, this study offers a practical framework for local environmental and public health authorities to design more effective groundwater monitoring and management strategies.

RESEARCH METHODS

Study Area

The study was conducted in a rural agricultural area in Indramayu District, West Java Province, Indonesia where most residents depend on groundwater from household wells for daily water needs. The area is characterized by mixed land use, including residential settlements, rice fields, vegetable farms, livestock activities, and small drainage channels. Most households use septic tanks for domestic wastewater disposal. The distance between wells and septic tanks varies among households, creating different levels of contamination risk. This study employed a descriptive-observational cross-sectional design. Data were collected during the dry season (August 2024) to minimize the confounding effect of seasonal rainfall variability on groundwater quality parameters. Data collection was conducted with prior informed consent from all participating households. The study was conducted in accordance with applicable ethical guidelines for environmental research involving community-based water sampling.

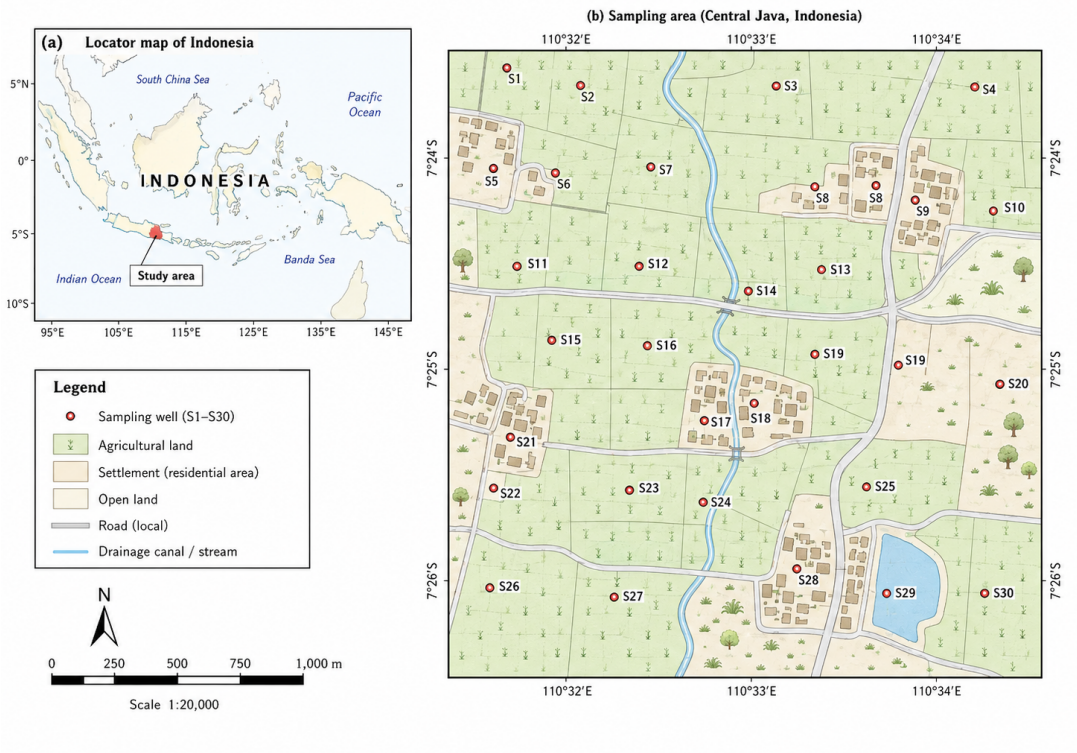


Figure 1. *The sampling area*

The figure shows the location of the groundwater sampling area used in this study. Panel ***(a)*** *presents the locator map of Indonesia, with the study area highlighted in Central Java. Panel* ***(b)*** *illustrates the detailed distribution of groundwater sampling points within the rural agricultural area. A total of* ***30 household wells (S1–S30)*** *were selected as sampling points. The map also shows the surrounding land-use characteristics, including agricultural land, residential settlements, open land, local roads, and drainage canals/streams. The distribution of sampling*

points was designed to represent different environmental conditions and potential contamination sources, particularly areas close to agricultural activities, residential sanitation systems, and surface drainage.

Sampling Design

Groundwater samples were collected from 30 household wells selected purposively based on their location, depth, surrounding land use, and distance from potential pollution sources. The sampling points were divided into three categories: wells located near agricultural land, wells located near residential sanitation systems, and wells located relatively far from visible pollution sources. Each sample was collected using sterilized bottles and labeled according to sampling location.

Physicochemical Analysis

Several physicochemical parameters were measured directly in the field, including temperature, pH, total dissolved solids, electrical conductivity, salinity, and dissolved oxygen. Field measurements were conducted using a portable multi-parameter water quality meter (WQC-22A, TOA-DKK Corporation, Japan), which simultaneously measures pH, temperature, dissolved oxygen, electrical conductivity, TDS, and salinity. Chemical parameters such as nitrate, phosphate, iron, and manganese were analyzed in the laboratory using standard analytical procedures in accordance with Standard Methods for the Examination of Water and Wastewater (*APHA. (2017). Standard Methods for the Examination... - Google Scholar*, n.d.) using a UV-Vis spectrophotometer (Shimadzu UV-1280) for colorimetric determination of nitrate (cadmium reduction method), phosphate (ascorbic acid method), iron (phenanthroline method), and manganese (periodate oxidation method). These parameters were selected because they are commonly associated with groundwater quality, agricultural activities, and domestic pollution.

Microbiological Analysis

Microbiological quality was assessed using total coliform as an indicator parameter. Water samples for microbiological analysis were collected in sterile bottles and transported to the laboratory under controlled temperature conditions (≤4°C) within six hours of collection. The presence and enumeration of total coliform was conducted using the membrane filtration method in accordance with (*APHA. (2017). Standard Methods for the Examination... - Google Scholar*, n.d.) with results expressed in Most Probable Number per 100 mL (MPN/100 mL). The membrane filtration method was applied consistently to all 30 samples to ensure methodological standardization and comparability of results.

Data Analysis

The results were compared with applicable drinking-water quality standards and international guideline values. Descriptive statistics, including minimum, maximum, mean, and standard deviation, were calculated for each parameter. Spatial interpretation was conducted by comparing water quality across different well categories. Wells with parameter values exceeding recommended limits were identified as potential risk points.

RESULTS AND DISCUSSION

Physicochemical Characteristics of Groundwater

The physicochemical characteristics of groundwater samples varied across the study area. The measured parameters included pH, temperature, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), salinity, nitrate, phosphate, iron, manganese, and total

coliform. Overall, most groundwater samples were within acceptable ranges for domestic use. However, several samples showed elevated nitrate, TDS, and total coliform values, particularly in wells located near agricultural land, residential settlements, and drainage channels.

Table 1. Descriptive Statistics of Groundwater Quality Parameters

Parameter	Unit	Minimum	Maximum	Mean	Standard Deviation	Guideline Value
pH	-	6.20	7.80	6.91	0.41	6.5–8.5
Temperature	°C	26.10	30.40	28.15	1.12	-
TDS	mg/L	145.00	780.00	386.70	154.30	500
Electrical conductivity	µS/cm	290.00	1,560.00	773.40	308.50	-
Dissolved oxygen	mg/L	3.10	6.80	4.92	0.88	-
Salinity	ppt	0.10	0.70	0.32	0.14	-
Nitrate	mg/L	2.40	62.50	24.85	14.76	50
Phosphate	mg/L	0.05	1.85	0.64	0.43	-
Iron	mg/L	0.03	1.25	0.38	0.31	0.3
Manganese	mg/L	0.01	0.47	0.15	0.11	0.4
Total coliform	MPN/100 mL	0.00	240.00	56.70	67.20	0

Source: Data Processed

Based on Table 1, pH values ranged from 6.20 to 7.80, indicating that groundwater in the study area was generally slightly acidic to neutral. Some wells had pH values below the recommended range, especially those located near agricultural land. The TDS values ranged from 145 to 780 mg/L, with several samples exceeding the recommended limit of 500 mg/L. High TDS values may indicate the presence of dissolved minerals, agricultural residues, or domestic wastewater infiltration.

Nitrate concentrations ranged from 2.40 to 62.50 mg/L. Several samples exceeded the recommended value of 50 mg/L, suggesting possible contamination from fertilizer application, livestock waste, or septic tank leakage. Iron concentrations also exceeded the guideline value in some samples, which may affect the taste, color, and acceptability of groundwater for household use. Total coliform was detected in several wells, indicating microbiological contamination and possible exposure to domestic or animal waste.

Groundwater Quality Based on Sampling Location

Groundwater quality differed according to the surrounding land-use characteristics (He et al., 2020). Wells located near agricultural land tended to have higher nitrate concentrations, while wells near residential settlements showed higher total coliform contamination. Wells located near drainage channels also showed relatively higher TDS and microbial contamination.

Table 2. Groundwater Quality Condition Based on Sampling-Point Category

Sampling Point Category	Number of Samples	Dominant Contamination Indicator	Possible Pollution Source	General Water Quality Condition
Near agricultural land	12	Nitrate, EC, TDS	Fertilizer use, agricultural runoff	Moderate contamination risk
Near residential settlements	10	Total coliform, nitrate	Septic tanks, domestic wastewater	High microbiological risk
Near drainage canal/stream	5	TDS, total coliform	Surface runoff, drainage infiltration	Moderate to high risk
Relatively far from pollution sources	3	Low contamination	Limited anthropogenic input	Relatively good quality

Source: Data Processed

Table 2 shows that groundwater contamination was strongly associated with land-use activities around the sampling points. Wells located near residential settlements showed the highest microbiological risk due to the presence of septic tanks, household wastewater, and poor drainage systems. Meanwhile, agricultural wells were more affected by nitrate contamination, which may originate from nitrogen-based fertilizers and organic manure.

Distribution of Nitrate Concentration

Nitrate was one of the most important chemical indicators in this study because it is closely related to agricultural activities and sanitation conditions. Wells located near agricultural land and residential areas showed higher nitrate concentrations than wells located farther from potential pollution source

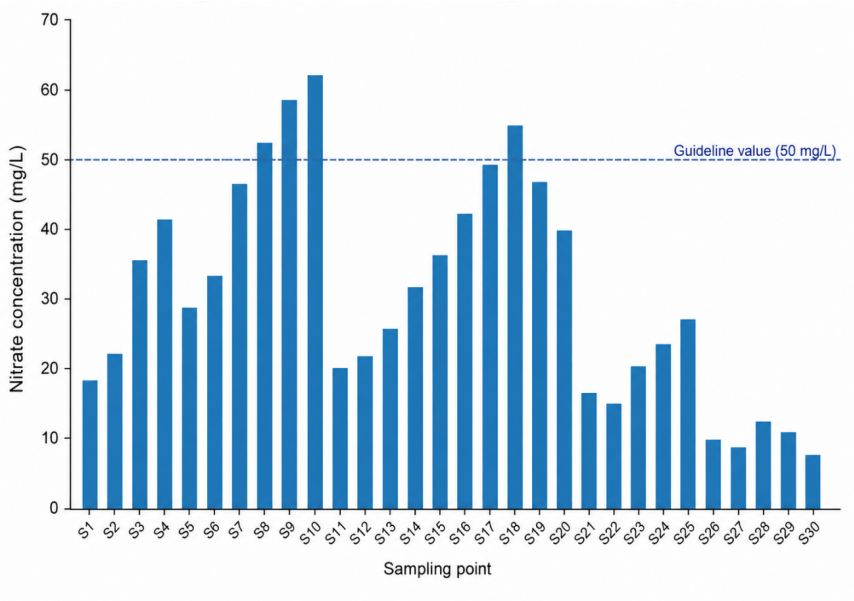


Figure 2. Nitrate Concentration in Groundwater Samples

The figure illustrates the distribution of nitrate concentration across 30 groundwater sampling points. The highest nitrate values were found at sampling points S8, S9, S10, and S18, which were located near agricultural land and residential settlements. Several sampling points exceeded the recommended nitrate threshold of 50 mg/L, indicating potential contamination from fertilizer application, septic tank leakage, or domestic wastewater infiltration.

The nitrate concentration varied among sampling points. The highest nitrate concentration was recorded at S10, followed by S9, S18, and S8. These sampling points were located near agricultural areas and residential settlements, suggesting that both fertilizer application and domestic sanitation systems may contribute to nitrate contamination. In contrast, lower nitrate concentrations were recorded at S26, S27, S29, and S30, which were relatively distant from major pollution sources.

Microbiological Quality of Groundwater

Microbiological analysis showed that total coliform was detected in several groundwater samples. The presence of total coliform indicates possible contamination from human or animal waste. This condition is important because contaminated groundwater may pose health risks if consumed without treatment.

Table 3. Total Coliform Level in Groundwater Samples

Coliform Category	Total Coliform Value	Number of Samples	Percentage	Water Safety Interpretation
Safe	0 MPN/100 mL	8	26.67%	Meets microbiological requirement
Low contamination	1–50 MPN/100 mL	9	30.00%	Requires treatment before consumption
Moderate contamination	51–100 MPN/100 mL	7	23.33%	Unsafe without treatment
High contamination	>100 MPN/100 mL	6	20.00%	High public health risk

Source: Data Processed

Table 3 indicates that only 8 samples, or 26.67%, met the microbiological safety requirement. Most samples showed some level of coliform contamination, indicating that groundwater in the study area may not be safe for direct consumption without treatment. Samples with high coliform levels were generally located near septic tanks, drainage channels, and densely populated settlement areas.

Comparison Between Sampling Categories

To better understand the relationship between land use and groundwater quality, selected parameters were compared across four sampling categories. The comparison included average nitrate, TDS, and total coliform values.

Table 4. Average Groundwater Quality Parameters by Sampling Category

Sampling Category	Average Nitrate (mg/L)	Average TDS (mg/L)	Average Total Coliform (MPN/100 mL)	Risk Level
Agricultural land	38.60	428.50	42.30	Moderate
Residential settlement	41.20	465.80	96.40	High
Drainage canal/stream	34.75	512.60	88.70	High
Low-risk/open area	13.50	215.40	8.60	Low

Based on Table 4, wells located near residential settlements had the highest average total coliform level, while wells near drainage canals showed the highest average TDS. Agricultural wells showed relatively high nitrate concentration, reflecting the influence of fertilizer and agricultural runoff. Wells located in low-risk or open areas showed lower contamination levels across all selected parameters.

Spatial Pattern of Groundwater Contamination

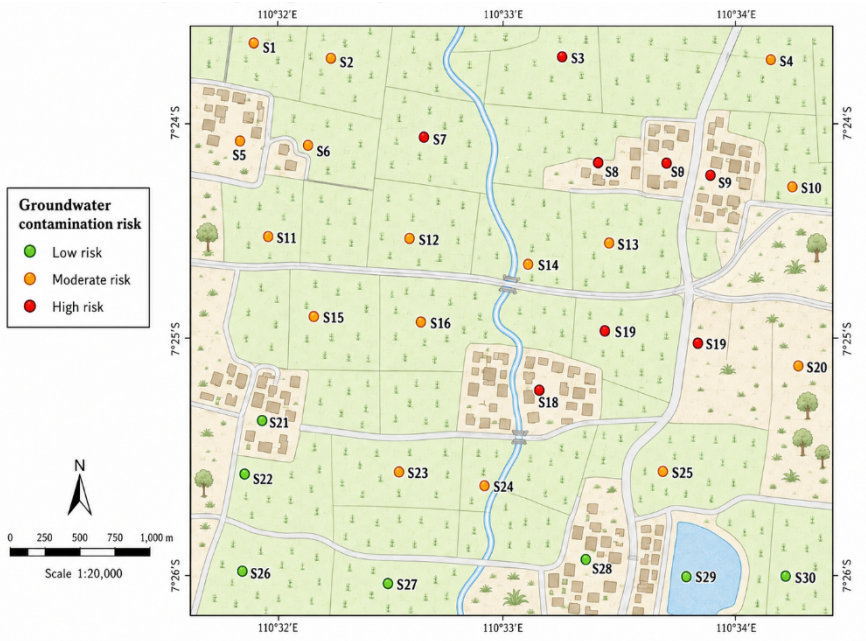


Figure 3. Spatial pattern of Groundwater Contamination Risk

The figure presents the classification of groundwater sampling points based on contamination risk. High-risk points were mainly distributed near residential settlements, agricultural land, and drainage channels. Moderate-risk points were found in areas influenced by agricultural activities but with lower microbiological contamination. Low-risk points were generally located farther from visible pollution sources.

The spatial pattern of contamination indicates that groundwater quality was closely related to surrounding environmental conditions. High-risk sampling points were concentrated in areas with intensive human activity, particularly near residential settlements and agricultural land. This suggests that groundwater contamination in the study area is not randomly distributed but is

associated with specific land-use and sanitation characteristics.

Summary of Results

The results indicate that groundwater quality in the study area was affected by both agricultural and domestic activities. Nitrate contamination was mainly associated with agricultural land and septic tank leakage, while microbiological contamination was strongly related to residential sanitation and drainage conditions. Although some wells showed acceptable physicochemical quality, the presence of total coliform in many samples indicates that groundwater should not be consumed directly without treatment. These findings highlight the need for regular monitoring, improved sanitation infrastructure, and community awareness regarding safe groundwater use.

Discussion

The results of this study indicate that groundwater quality in the rural agricultural area was influenced by both agricultural activities and domestic sanitation conditions. Based on Table 1, most physicochemical parameters were still within acceptable ranges for domestic use; however, several wells showed elevated concentrations of total dissolved solids (TDS), nitrate, iron, manganese, and total coliform. This finding suggests that groundwater contamination in the study area was not caused by a single source, but by the interaction between land use, well location, sanitation infrastructure, and local hydrogeological conditions. Groundwater contamination is often difficult to detect without laboratory testing because many pollutants are invisible, odorless, and may accumulate gradually over time (Wang et al., 2023) Therefore, groundwater-quality assessment is essential to identify potential environmental and public health risks.

The pH values ranged from 6.20 to 7.80, indicating slightly acidic to neutral groundwater conditions. Although most samples were still within the recommended range, several wells had pH values below 6.5. Slightly acidic groundwater may be influenced by soil characteristics, organic matter decomposition, fertilizer application, and natural geochemical reactions. pH is an important parameter because it can influence the solubility and mobility of metals such as iron and manganese in groundwater systems (*APHA. (2017). Standard Methods for the Examination... - Google Scholar*, n.d.) This condition may explain why some samples in Table 1 showed iron concentrations above the guideline value. Elevated iron concentration does not always indicate severe toxicological risk, but it can reduce water acceptability because it may affect taste, odor, color, and household usability (chronicle & 2011, 2008)

It is important to note, however, that elevated iron and manganese concentrations in shallow groundwater can originate from both geogenic and anthropogenic sources. Geogenically, iron and manganese are naturally abundant in the alluvial and volcanic sedimentary formations characteristic of lowland West Java, including Indramayu District. Under reducing conditions or at lower pH, these metals dissolve from sediment minerals and enter the groundwater through natural hydrogeochemical processes (Appelo & Postma, 2004; Islam & Mostafa, 2023; Podgorski et al., 2022). Anthropogenically, the infiltration of organic-rich wastewater from septic tanks, livestock pens, and agricultural runoff can promote reducing conditions that further mobilize these metals. In the present study, the co-occurrence of elevated iron with slightly acidic pH and proximity to organic pollution sources suggests a combined geogenic-anthropogenic origin. Manganese concentrations reached a maximum of 0.47 mg/L in some samples, exceeding the

(chronicle & 2011, 2008) guideline value of 0.4 mg/L. Although manganese exceedance was observed only in selected samples, this finding warrants attention because long-term manganese exposure above recommended levels has been associated with neurological effects, particularly in children (chronicle & 2011, 2008) This manganese exceedance, which was insufficiently discussed in earlier drafts, is now explicitly noted as a co-contaminant of concern alongside nitrate and total coliform in the groundwater of Indramayu District.

TDS values ranged from 145 to 780 mg/L, with several samples exceeding the guideline value of 500 mg/L. Higher TDS values were particularly observed in wells located near residential settlements and drainage channels. This result is supported by Table 4, which shows that wells near drainage canals had the highest average TDS value of 512.60 mg/L. High TDS may reflect the accumulation of dissolved ions from soil minerals, agricultural residues, domestic wastewater, and surface runoff infiltration. Although TDS does not directly identify a specific pollutant source, elevated TDS indicates that groundwater has received additional dissolved substances from the surrounding environment (Qureshi et al., 2021) Therefore, wells with high TDS should receive more attention because they may indicate broader contamination pressure from land-use activities.

Nitrate was one of the most critical chemical indicators in this study. As shown in Figure 2, nitrate concentrations varied substantially among sampling points, ranging from 2.40 to 62.50 mg/L. Several sampling points, particularly S8, S9, S10, and S18, exceeded the recommended guideline value of 50 mg/L. This condition indicates potential contamination from fertilizer application, livestock waste, septic tank leakage, and domestic wastewater infiltration. The intensification of chemical fertilizer use in agricultural areas has been documented globally as a major driver of nitrate accumulation in groundwater, with studies reporting that average nitrate concentrations in surface and groundwater bodies have risen by approximately 36% since 1990 due to increased agricultural chemical inputs (Mahanta et al., 2022). Nitrate contamination is commonly associated with agricultural and residential land use because nitrate is highly soluble and can easily leach into shallow groundwater systems (Verma et al., 2023) In agricultural areas, excessive nitrogen-based fertilizer application may increase nitrate accumulation in soil.

The comparison among sampling categories in Table 4 further supports the influence of land use on nitrate distribution. Wells located near agricultural land had an average nitrate concentration of 38.60 mg/L, while wells near residential settlements had a slightly higher average value of 41.20 mg/L. This finding suggests that nitrate contamination in the study area was not only related to agricultural activities but also to domestic sanitation systems. In rural settlements, septic tanks and household wastewater may release nitrogen compounds into the subsurface environment, especially when wells are located too close to sanitation facilities or when septic systems are poorly constructed and poorly maintained (chronicle & 2011, 2008) Similar findings have been reported in groundwater studies showing that agricultural runoff, domestic wastewater, and septic system leakage are major drivers of nitrate contamination in shallow aquifers (Verma et al., 2023)

Microbiological contamination was also a major concern in this study. Table 3 shows that only 8 samples, or 26.67%, met the microbiological safety requirement of 0 MPN/100 mL. Meanwhile, 22 samples showed some level of total coliform contamination, ranging from low to high contamination categories. The proportion of non-compliant wells observed in this study is broadly consistent with findings from other groundwater studies in Indonesia, where E. coli was detected in the majority of self-supply sources.The presence of total coliform indicates possible

contamination from human waste, animal waste, septic tanks, drainage channels, or surface runoff. According to(chronicle & 2011, 2008) microbiological safety is a fundamental requirement for drinking-water quality because pathogenic contamination can cause acute health effects, particularly gastrointestinal diseases. Therefore, groundwater containing total coliform should not be consumed directly without appropriate treatment.

The high microbiological contamination found in residential and drainage-related wells is consistent with the spatial pattern presented in Figure 3. High-risk sampling points were concentrated around residential settlements, agricultural land, and drainage canals, particularly S7, S8, S9, S10, S17, S18, and S19. These sampling points represent areas where nitrate, TDS, and/or total coliform levels were relatively high. This spatial pattern indicates that groundwater contamination was not randomly distributed, but closely associated with environmental pressure from human activities. Wells located near settlements are more vulnerable because septic tanks, household wastewater, and poor drainage systems can create direct contamination pathways into shallow groundwater (Wang et al., 2023); (chronicle & 2011, 2008)

The results also show that wells located relatively far from visible pollution sources had better water quality. Table 4 shows that low-risk or open-area wells had lower average nitrate concentration, lower TDS, and lower total coliform levels compared with wells near agricultural land, residential settlements, and drainage canals. This result supports the importance of safe well placement and adequate distance between wells and potential contamination sources. Proper well construction, well covering, elevation of well rims, and protection from surface runoff are important preventive measures to reduce microbial and chemical contamination (chronicle & 2011, 2008) These measures are particularly important in rural areas where household wells are commonly used as the main source of water.

From a public health perspective, the combination of elevated nitrate and total coliform contamination is concerning. Nitrate contamination is generally associated with long-term exposure risks, while microbial contamination may cause more immediate health problems. High nitrate concentration in drinking water can pose health risks, particularly for infants and vulnerable populations, while microbial contamination may increase the risk of waterborne diseases (chronicle & 2011, 2008) (Wang et al., 2023) also emphasized that linking groundwater quality to health is important because groundwater pollution often remains invisible until its effects appear in human health or environmental degradation.

Phosphate concentrations in this study ranged from 0.05 to 1.85 mg/L, with a mean of 0.64 mg/L (Table 1). Although no WHO or national drinking-water guideline threshold for phosphate in groundwater has been established for health-based purposes, elevated phosphate in groundwater is ecologically significant as a nutrient pollutant. Phosphate in groundwater commonly originates from phosphate-based fertilizers, animal manure, detergents, and septic tank effluents (Carpenter et al., n.d.) In the context of the present study area, where intensive agricultural activity and domestic wastewater infiltration are prevalent, elevated phosphate concentrations in several wells reflect the broader pattern of nutrient contamination. While phosphate does not pose a direct acute toxicological risk at the levels observed in this study, its presence in groundwater serves as an indicator of anthropogenic nutrient loading and warrants monitoring alongside nitrate to assess cumulative agricultural contamination pressure.Overall, the results demonstrate that groundwater quality management in rural agricultural areas should not rely only on occasional laboratory testing. Instead, it should involve integrated monitoring of chemical and microbiological parameters, land-use control, sanitation improvement, and

community education. The systematic review by (Mbae et al., 2024) demonstrated that the risk of groundwater contamination from onsite sanitation systems is governed by source-pathway-receptor interactions and is substantially reduced when well setback distances and protective construction standards are enforced. Regular monitoring should prioritize high-risk wells identified in Figure 3, especially those located near residential settlements, agricultural fields, and drainage channels. Household-level treatment, such as boiling, filtration, or other appropriate water-treatment technologies, should also be encouraged before groundwater is used for drinking purposes (chronicle & 2011, 2008)

This study provides evidence that rural groundwater contamination is strongly influenced by local environmental conditions. Agricultural activities contributed mainly to nitrate enrichment, while residential sanitation and drainage systems were more closely associated with microbiological contamination. Therefore, groundwater protection requires coordinated action among local government, environmental agencies, public health officers, and community members. The findings support the need for preventive groundwater-management policies, especially in rural areas where household wells remain the main source of domestic water supply.

CONCLUSION

This study successfully achieved its stated objectives of assessing the physicochemical and microbiological quality of groundwater in a rural agricultural area in Indramayu District, West Java Province, Indonesia, and evaluating its implications for public health. All three research objectives determining whether groundwater meets drinking-water quality standards, identifying contamination sources, and providing management recommendations were addressed based on analysis of 30 household well samples. The results demonstrate that groundwater quality in the study area is compromised by both agricultural and domestic pollution sources, with nitrate and total coliform contamination constituting the most critical public health concerns. Most physicochemical parameters were within acceptable limits; however, TDS exceedances in wells near drainage channels, iron exceedances in acidic wells, and isolated manganese exceedances indicate that chemical quality is heterogeneous and location-dependent. Microbiological contamination was widespread, with only 26.67% of samples meeting the 0 MPN/100 mL standard, confirming that most groundwater in the study area is unsafe for direct consumption without treatment. Spatially, high-risk wells clustered near residential settlements, agricultural fields, and drainage channels, confirming that contamination is spatially structured and linked to human activity patterns.

This study has several limitations that should be acknowledged. First, sampling was conducted only during the dry season (August 2024); seasonal variation in groundwater quality, particularly during the wet season when surface runoff is higher, was not captured. Second, the study employed purposive sampling of 30 wells, which, while appropriate for this exploratory-descriptive study, limits the generalizability of findings to the broader district. Third, microbiological testing was limited to total coliform; specific fecal coliform and Escherichia coli testing, which would provide stronger evidence of fecal contamination pathways, was not performed. Fourth, no formal quantitative Water Quality Index (WQI) or health risk assessment (HRA) was calculated; the health risk interpretation in this study is therefore qualitative, based on comparison with WHO guideline values. Fifth, hydrogeological data, including aquifer depth, hydraulic conductivity, and groundwater flow direction, were not collected, which limits the mechanistic interpretation of contamination pathways.

Preventive and management recommendations include: regular groundwater-quality monitoring for wells near agricultural fields, septic tanks, and drainage channels; improved well construction standards consistent with national regulations (Permenkes No. 2 Tahun 2023); maintenance of adequate setback distances between wells and sanitation facilities; promotion of household water treatment (boiling, filtration) prior to consumption; and community education on safe water management. Future research should address the identified limitations by incorporating multi-seasonal sampling, E. coli-specific testing, formal WQI and HRA calculations, hydrogeological profiling, and expanded sample coverage to produce a more comprehensive assessment of groundwater contamination risk in Indramayu District and similar agricultural regions of Indonesia.

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