JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2026, 27(9), 503–511
https://doi.org/10.12911/22998993/224189
ISSN 2299–8993, License CC-BY 4.0

Received: 2026.04.30
Accepted: 2026.07.15
Published: 2026.08.01

Assessment of heavy metal and bacterial contamination in groundwater resources in Dong Nai Province, Vietnam

Viet The Ho[1*], Duc Thao Tran[1], Thi Kim Anh Ngo[1], Huu Quang Le[2]

[1] Ho Chi Minh City University of Industry and Trade (HUIT), 140 Le Trong Tan, Tay Thanh Ward, Ho Chi Minh City, Vietnam
[2] Institute for Public Policy and Rural Development, 45 Dinh Tien Hoang Street, Sai Gon ward, Ho Chi Minh City, Vietnam
* Corresponding author's email: thevh@huit.edu.vn

ABSTRACT

Dong Nai Province, located in southeastern Vietnam, has experienced rapid industrial and agricultural development, accompanied by increasing pressure on groundwater resources. Excessive groundwater extraction raises concerns regarding water quality, agricultural sustainability, and public health. This study assessed groundwater contamination by nitrate, selected heavy metals, and bacterial indicators across the province. A total of 55 groundwater samples were analyzed for nitrate, arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), total coliforms, and *Escherichia coli* (*E. coli*). The mean nitrate concentration was 18.02 mg/L, with the highest levels observed in Bien Hoa City. Lead contamination was widespread, exceeding drinking-water standards at several locations, while elevated As and Cd concentrations were detected only at a limited number of sites. Bacterial contamination, indicated by total coliforms and *E. coli*, was detected in multiple districts, particularly in Long Khanh. Although the results primarily indicate associations rather than direct causal relationships, they highlight potential risks to groundwater used for domestic supply and agricultural irrigation. The findings provide evidence to support improved groundwater monitoring, agricultural water management, and policy development aimed at safeguarding rural livelihoods and sustainable agricultural development in Dong Nai Province.

Keywords: bacteria, contamination, Dong Nai Province, groundwater, heavy metals.

INTRODUCTION

Dong Nai Province plays a vital economic role in the Southeast region of Vietnam. Although widely recognized for its industrial development, the province also maintains a substantial agricultural area. While agriculture contributes only about 6% to Dong Nai's gross domestic product (GDP), it remains essential for sustaining the livelihoods of more than 54.7% of the rural population (Le, 2025). Traditionally, local farmers have relied on surface water for both agricultural and domestic activities. However, the combined effects of climate change and population growth have intensified water scarcity across large parts of the province. As a result, unregulated groundwater extraction has increased as communities seek to sustain livelihoods and support economic development.

Prolonged dry seasons and insufficient rainfall have depleted irrigation reservoirs, reducing the availability of surface water and increasing dependence on groundwater resources (Pham et al., 2024). Excessive groundwater abstraction has also been linked to potential contamination, including the presence of heavy metals in drinking water supplies (Jolk et al., 2010). Agricultural land use further influences groundwater quality, as demonstrated by elevated levels of nitrate, ammonium, potassium, and electrical conductivity in regions such as the Yucatan Peninsula, Mexico (Smith et al., 2020). Such contamination poses serious public health risks and may contribute to the incidence of diseases, including diabetes and cancer (Chang et al., 2017).

Monitoring by the Dong Nai Environmental Monitoring and Engineering Center indicates that several areas in the province are experiencing declining groundwater levels alongside significant pollution. Recent assessments by the Vietnam Department of Water Resources Management, based on 33 monitoring projects across five districts, show a substantial decrease in groundwater levels since 2014, accompanied by worrying deterioration in key domestic water quality indicators (DWRM, 2025). Dong Nai is home to 32 industrial parks, numerous industrial clusters, and active craft villages. Rapid industrial expansion has generated various environmental challenges, including pollution, resource depletion, and negative impacts on community livelihoods. Among these challenges, the pollution and depletion of underground water resources have become particularly critical concerns.

Heavy metal sludge discharged into waterways represents a major pollution source and is one of the most common forms of industrial waste in Southeast Asia. Malaysia alone produces approximately 1,740,000 metric tons of such waste annually (Ismanto et al., 2023). Industrial effluents are widely recognized as key contributors to heavy metal contamination. Doan and colleagues (2013) reported that Dong Nai Province and nearby areas have faced declines in groundwater reserves and gradual deterioration in water quality due to unsustainable exploitation and inadequate management. Saltwater intrusion has further aggravated these problems, affecting daily life and agricultural productivity across the region.

The objective of this study is to assess the extent of groundwater contamination in Dong Nai Province. The findings aim to provide essential insights for provincial management agencies to support the sustainable use of groundwater resources while minimizing the risks of pollution and depletion.

METHODOLOGY

Study area and sampling strategy

This study was conducted in Dong Nai Province, southeastern Vietnam, with sampling locations shown in Figure 1. A total of 55 groundwater samples were collected from drilled wells distributed across the surveyed districts. The sampling design was intended to provide district-level coverage of areas where groundwater is used for domestic and agricultural purposes. Sampling sites were selected to represent different land-use contexts, including urbanized, industrial, peri-urban, and agricultural areas, while also considering field accessibility and the availability of active wells. Because the sampling campaign was designed as an exploratory assessment, the results should be interpreted as a spatial screening of groundwater quality rather than as a long-term monitoring dataset. Groundwater samples were collected following standard water sampling procedures. Sampling bottles were washed with detergent, rinsed with 10% hydrochloric acid, and thoroughly cleaned with double-distilled water to prevent contamination. Before sampling, groundwater was allowed to flow for several minutes to remove stagnant water and ensure representative collection. At each site, approximately 1.5 L of groundwater was collected in high-density polyethylene bottles and immediately sealed. Samples were stored in ice-cooled containers and transported to the laboratory, where they were kept at 4 °C until analysis. All analyses were conducted on the same day to ensure sample integrity.

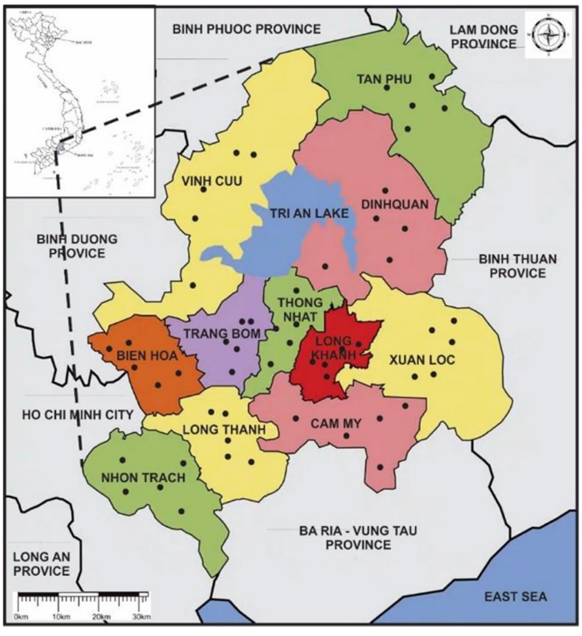

Figure 1. Groundwater sampling locations in Dong Nai Province. Black dots indicate groundwater sampling sites

Analysis of nitrate and heavy metal composition

Nitrate (NO_3^-) concentrations were analyzed using the ISO 7890-3:1988 spectrophotometric method. Nitrate was reduced to nitrite through a cadmium reduction column, and absorbance was measured at 540 nm. Calibration curves and appropriate quality-control procedures were applied throughout the analysis.

The concentrations of arsenic (As), mercury (Hg), lead (Pb), and cadmium (Cd) were measured using the SMEWW 3125B:2023 method with an inductively coupled plasma mass spectrometry (ICP-MS) system (NexION 1000, PerkinElmer, USA). Before analysis, groundwater samples were acidified with 1% ultrapure nitric acid (HNO_3), spiked with lutetium at 5 ppb as an internal standard, and filtered through 0.45 µm membrane filters. Analyses were performed in helium kinetic energy discrimination (KED) mode to reduce polyatomic interferences. The monitored isotopes included As (74.9216 amu), Cd (110.904 amu), Hg (201.971 amu), and Pb (207.977 amu), each measured with a dwell time of 50 ms per amu.

Calibration standards ranged from 0.25 to 25 ppb for As and Cd, 0.10 to 10 ppb for Hg, and 0.50 to 50 ppb for Pb. Limits of quantification (LOQ) were 1 ppb for As and Cd, 0.5 ppb for Hg, and 5 ppb for Pb. Each groundwater sample was analyzed in triplicate to ensure analytical reliability.

Analysis of bacterial contamination

All groundwater samples were analyzed on the day of collection to determine total coliform, fecal coliform, and *Escherichia coli* (*E. coli*) counts using standard culture-based methods. Samples were transported to the laboratory under aseptic, cold-chain conditions to prevent changes in microbial composition. Before analysis, each sample was diluted in 0.1% buffered peptone water at a 10:100 (v/v) ratio to obtain homogeneous test solutions.

The enumeration of coliforms and *E. coli* was carried out using the Most Probable Number (MPN) technique. Serial dilutions (10^{-1}, 10^{-2}, 10^{-3}) were prepared in buffered peptone water and inoculated into three sets of tubes containing 10 mL of Modified Lauryl Sulfate Tryptose (mLST) broth. Following incubation at 37 °C for 24-48 hours, tubes showing gas or color production were transferred to Brilliant Green Bile Broth (BGLB) and incubated under the same conditions for confirmation. Positive BGLB tubes were then inoculated into *E. coli* broth and incubated at 44.5 ± 0.2 °C for 24 hours.

Presumptive *E. coli* isolates were further confirmed by streaking onto Eosin Methylene Blue (EMB) agar and Plate Count Agar (PCA). The number of positive tubes at each dilution level was recorded, and MPN values were calculated using standard MPN tables. Results were expressed as MPN per 100 mL of groundwater sample (Armah, 2014).

Statistical analysis

Descriptive statistical analyses were performed to summarize the distribution of nitrate, heavy metals, and bacterial indicators across the groundwater samples. The results were expressed using appropriate summary statistics, including mean values and concentration ranges, to describe spatial variations among districts. District-level differences in nitrate concentrations were evaluated using one-way analysis of variance (ANOVA), followed by Tukey's post hoc test when significant differences were detected. Different letters shown in the Figures 2 indicate statistically significant differences among districts at $P < 0.05$. Pearson's product-moment correlation analysis was conducted to evaluate linear associations among nitrate, heavy metals, and bacterial indicators. Correlation coefficients were interpreted cautiously as indicators of association rather than evidence of direct causation. All statistical tests were considered significant at $P < 0.05$. Because the dataset was derived from a single sampling campaign with limited temporal replication, the statistical analyses were used primarily to identify spatial patterns and potential relationships requiring further investigation rather than to establish long-term trends or definitive source-effect relationships.

RESULTS AND DISCUSSION

Nitrate pollution

Nitrate is a key indicator of groundwater pollution associated with urban, industrial, and agricultural activities, and its concentrations often exceed natural background levels. The nitrate concentrations measured in this study are shown in Figure 2.

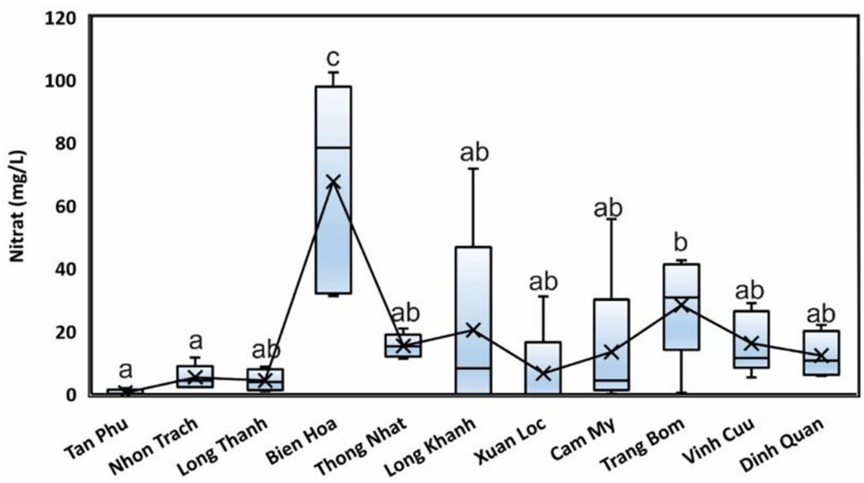

Figure 2. Nitrate contamination in groundwater of Dong Nai Province. Different letters indicate statistically significant differences among districts at $P < 0.05$

Groundwater nitrate (NO_3^-) contamination can be associated with livestock waste, septic systems, and fertilizer use in agricultural production. Agricultural practices such as plowing, fallowing, and irrigation can enhance nitrate dissolution and mobility within the soil profile (León-Gómez et al., 2020). In this study, the mean nitrate concentration across Dong Nai Province was 18.02 mg/L, which is nearly 90 times higher than the levels reported by Buschman and colleagues (2008). Except for Tan Phu, all surveyed districts recorded nitrate concentrations exceeding the permissible limits set by the Vietnam Technical Regulation on Groundwater Quality (NTRGWQ, 2015). However, the comparisons with previous studies should be interpreted cautiously because groundwater chemistry can vary substantially with aquifer characteristics, sampling depth, land use, season, and analytical approach.

The elevated nitrate levels observed in the province may reflect the combined influence of agricultural and livestock activities, together with possible inputs from domestic wastewater and urban runoff. However, the present study did not include isotopic tracers or source-specific measurements; therefore, the exact origins of nitrate contamination cannot be confirmed. Previous research has shown that land-use patterns can influence groundwater nitrate concentrations, with higher levels often reported in agricultural areas than in non-agricultural zones (Smith et al., 2020). In this context, land-use change and intensified agricultural production should be regarded as plausible contributing factors rather than confirmed causal sources of nitrate accumulation in Dong Nai groundwater.

Heavy metal concentrations

The concentrations of arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) measured in groundwater samples are presented in Figure 3.

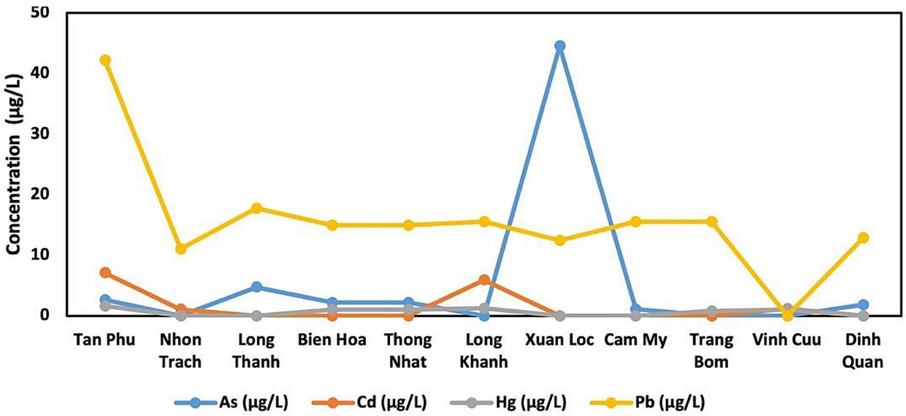

Figure 3. Heavy metal contamination in groundwater at Dong Nai Province

Among the four metals, Pb exhibited the highest concentrations across most locations, with a pronounced peak in Tan Phu that exceeded 40 µg/L. Mercury levels remained consistently low throughout the study area, suggesting limited Hg contamination. Arsenic concentrations showed moderate spatial variability, with the highest value reported in Xuan Loc, whereas Cd levels were generally low, with slight increases detected in Cam My and Tan Phu.

The elevated Pb concentrations observed in Tan Phu and several other districts may reflect the influence of nearby industrial activities, traffic emissions, waste disposal practices, or local hydrogeochemical conditions; however, additional investigations would be required to confirm specific sources and pathways. These factors are plausible contributors based on patterns reported in previous studies, but the present dataset cannot determine direct causality. The higher As concentration in Xuan Loc could be related to natural geogenic conditions, agricultural inputs, or localized aquifer characteristics. Similar localized As contamination patterns have been reported in other regions, including the findings of Tabassum and colleagues (2019), who noted that arsenic-rich groundwater can occur in specific sampling contexts. Such comparisons are useful for context but should be interpreted with caution because hydrogeological settings, well depths, land-use conditions, and sampling designs differ among studies.

In contrast, the relatively uniform and low concentrations of Hg and Cd suggest limited contamination from these metals within the sampled wells, although this interpretation is constrained by the single sampling campaign and district-level sampling density. Despite these lower concentrations, Pb and As remain of particular concern given their toxicity and the observed exceedances of guideline values. For comparison, As levels in Dong Nai were lower than those reported in Hoang Tay commune, Kim Bang district (Ha Nam Province), where concentrations ranged from 0.06 to 0.178 mg/L (Hai et al., 2024). However, this comparison should be considered contextual rather than definitive because the two studies differ in hydrogeological setting, sampling context, and spatial scale. On a broader scale, Ghosh and colleagues (2019) identified countries such as Bangladesh, India, Thailand, Taiwan, and Vietnam as among the regions affected by arsenic contamination in groundwater.

The heavy metals assessed in this study, consisting of As, Cd, Hg, and Pb, are well known for their adverse effects on human health, including DNA damage, cancer risk, and neurological impairment. Samples exceeding recommended WHO limits are summarized in Table 1. Significant arsenic contamination has also been documented elsewhere in Vietnam; Nghiem and colleagues (2019) reported that 39.3% of well water samples in the Red River Delta exceeded the WHO guideline value of 50 µg/L. Heavy metals may originate from industrial processes, agricultural activities, vehicle emissions, and domestic or electronic waste, as reported in a previous study (León-Gómez et al., 2020).

Overall, the results highlight localized but concerning contamination patterns in Dong Nai Province, especially for Pb and As, emphasizing the need for continued monitoring and targeted interventions to protect groundwater quality.

Table 1. Average values of heavy metal concentrations in groundwater in Dong Nai Province

District	As (µg/L)	Cd (µg/L)	Hg (µg/L)	Pb (µg/L)
Tan Phu	2.65	7.9*	1.62	42.25*
Nhon Trach	0	1.05	0	15.09*
Long Thanh	4.74	0	0	0
Bien Hoa	2.20	0	1.01	13.78*
Thong Nhat	0	0	1.91	0
Long Khanh	5.92	0	1.24	59.36*
Xuan Loc	44.55*	0	0	0
Cam My	1.11	0	0	0
Trang Bom	0	0	0.81	18.54*
Vinh Cuu	0	1.15	0.99	0
Dinh Quan	1.77	0	0	12.9*

Note: Bolded and asterisked values indicate concentrations exceeding the WHO (2024) drinking-water guideline values for As (10 µg/L), Cd (3 µg/L), Hg (6 µg/L), and Pb (10 µg/L).

Bacterial contamination

The concentrations of total coliforms and *E. coli* detected in groundwater across Dong Nai Province are shown in Figure 4. Coliform levels varied considerably among districts, with Long Khanh recording the highest concentration, exceeding 45,000 MPN/100 mL. Such elevated values indicate substantial fecal contamination and may reflect influences from agricultural runoff, untreated domestic wastewater, or inadequate sanitation systems. Differences in coliform levels across districts may also be related to well construction, as shallow wells are generally more susceptible to surface-derived contamination than deeper, protected boreholes. Moderate contamination was observed in Long Thanh and Trang Bom, while other districts exhibited comparatively low coliform concentrations. In contrast, *E. coli* levels remained consistently low throughout the study area, suggesting a limited presence of this specific pathogen.

Although coliform bacteria are not necessarily pathogenic, their occurrence serves as an indicator of potential contamination by harmful microorganisms. *E. coli*, in particular, is widely recognized as a marker of recent fecal pollution and is associated with illnesses such as intestinal infections, dysentery, hepatitis, typhoid fever, and cholera (Salaudeen et al., 2018). The detection of microbial contamination in groundwater therefore raises significant public health concerns, especially in communities that rely on untreated groundwater for domestic use.

Human and animal waste may be plausible sources of bacterial contamination in groundwater. Such contamination can occur through surface runoff from feedlots, pastures, and areas where waste accumulates, or through inadequately constructed wells that lack watertight casings or protective caps. Nevertheless, the present study did not directly trace microbial sources, and source attribution should therefore be considered tentative. Although *E. coli* concentrations in this study were relatively low, their presence highlights a potential risk of pathogenic contamination. Continued monitoring and the implementation of appropriate mitigation measures are essential to safeguard groundwater quality and protect public health, particularly in rural areas that depend heavily on groundwater resources.

Relationships among studied parameters

Heavy metal contamination in soils and groundwater often results from human activities, and these metals persist in the environment, posing long-term ecological and health risks. Their presence can disrupt microbial communities and reduce microbial diversity, as documented in previous studies (Sandaa et al., 1999; Tsezos, 2009). Correlation analysis revealed that nitrate had only weak or negligible associations with heavy metals and microbial indicators (Table 2), suggesting that nutrient pollution, potentially associated with fertilizer use, livestock waste, and wastewater inputs, may originate from sources different from those contributing to metal contamination. This finding is particularly relevant for agricultural regions where groundwater is used for irrigation, highlighting the need for improved nutrient management practices.

Stronger associations were observed among heavy metals. The strong Pb-Cd correlation (r = 0.91) and moderate relationships involving Hg may indicate co-occurrence or similar controlling factors, such as localized anthropogenic inputs, waste-related influences, or comparable

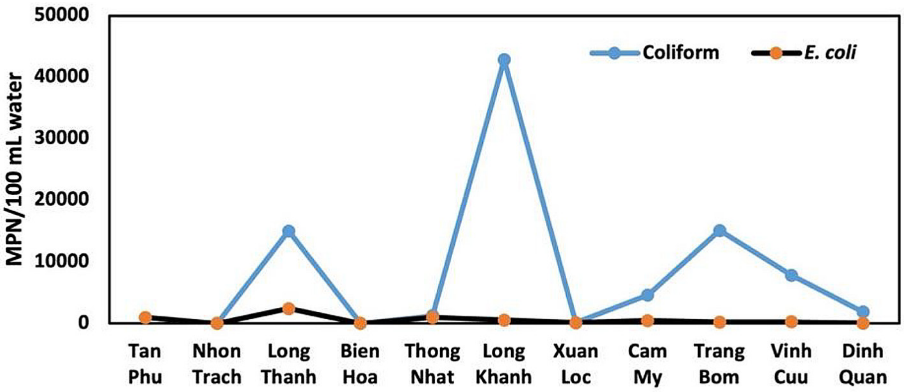

Figure 4. Bacterial contamination in groundwater in Dong Nai Province

Table 2. Correlation coefficients among the physicochemical characteristics of groundwater samples

Parameter	Nitrate	As	Cd	Hg	Pb	Coliform
As	-0.10					
Cd	-0.06	-0.04				
Hg	0.03	-0.10	0.40			
Pb	0.02	-0.06	0.91	0.26		
Coliform	-0.08	-0.07	-0.04	0.27	-0.11	
E. coli	-0.13	-0.08	0.10	0.08	0.03	0.11

geochemical behavior. However, correlation analysis alone cannot identify specific sources. These patterns underscore the need for more detailed source-apportionment studies and continued regulation of potential contaminant inputs to protect groundwater used by farming communities and rural households.

Microbial indicators showed weak correlations with chemical parameters, reflecting independent and possibly intermittent contamination pathways. This suggests that fecal pollution is influenced more by sanitation conditions, well construction, and land-use practices than by chemical water quality. For rural communities relying on shallow wells, these findings emphasize the need for improved sanitation infrastructure and regular monitoring.

Overall, the results suggest heterogeneous contamination patterns across the groundwater system. Nitrate contamination may be associated with agricultural activities and domestic wastewater inputs, while heavy metal contamination may reflect localized industrial, waste-related, traffic-related, or geogenic influences. These distinctions have practical implications for policy: effective groundwater protection in Dong Nai will require integrated management strategies that address agricultural nutrient use, improve sanitation and well protection, regulate potential industrial emissions, and strengthen monitoring systems to safeguard water supplies essential for irrigation, rural livelihoods, and public health.

Study limitations

This study has several limitations that should be considered when interpreting the findings. First, the groundwater samples were collected during a limited sampling campaign; therefore, the results may not fully capture seasonal variations in nitrate, heavy metals, or microbial indicators. Second, although the study included 55 samples across Dong Nai Province, the sampling density remains limited relative to the spatial heterogeneity of groundwater systems, land-use patterns, well depths, and local hydrogeological conditions. Third, the absence of long-term monitoring data restricts the ability to assess temporal trends and distinguish short-term fluctuations from persistent contamination patterns. Fourth, the study did not include source-tracing methods, such as isotopic analysis, microbial source tracking, or detailed hydrogeochemical modeling; therefore, interpretations regarding contamination sources should be considered indicative rather than confirmatory. Future studies should include multi-seasonal sampling, a denser sampling network, well-depth information, and long-term monitoring to better characterize spatial and temporal variability in groundwater quality.

CONCLUSIONS

This study provides an assessment of groundwater contamination in Dong Nai Province, identifying elevated levels of nitrate, selected heavy metals, and bacterial indicators across several districts. The results suggest that groundwater quality may be influenced by multiple factors, including agricultural activities, industrial expansion, sanitation conditions, and local hydrogeological characteristics. However, because the study was based on a single sampling campaign with limited sampling density and no long-term monitoring data, the findings should be interpreted as evidence of potential contamination risks rather than definitive proof of source-specific pollution pathways. The results highlight the need for strengthened groundwater monitoring, improved nutrient and waste management in farming systems, better well protection, and stricter oversight of potential industrial discharges. Groundwater plays a critical role in supporting irrigation, rural households, and local livelihoods; therefore, safeguarding its quality is essential for both agricultural productivity and public health. Future research should incorporate multi-seasonal sampling, higher spatial sampling density, source-tracing approaches, and long-term monitoring to better distinguish temporal variability from persistent contamination patterns. Strengthening water governance will be essential as Dong Nai seeks to balance agricultural growth with the potential impacts of ongoing industrial expansion and to ensure the long-term sustainability of groundwater resources.

Acknowledgements

The authors acknowledge the SEARCA International Foundation for Science and the Southeast Asian Regional Center for Graduate Study in Research and Development (SEARCA) for financial support through Seed Fund for Research and Training (SFRT) program under Ref. No. GBG 24-3806.

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