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Physicochemical and Microbiological Quality of Deep Well Water in Sitio Cabalawan, Barangay Rizal, Surigao City, Philippines: Implications for Domestic Water Safety and Public Health

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ABSTRACT: Groundwater from deep wells was the primary source of domestic water for many rural communities in the Philippines. However, routine groundwater quality monitoring remained limited, increasing the risk of exposure to physicochemical and microbiological contaminants. This study evaluated the quality of untreated deep-well water in Sitio Cabalawan, Barangay Rizal, Surigao City, Philippines. Water samples were collected from three groundwater supply configurations: a communal hand pump, a household hand pump, and a household faucet supplied through an elevated storage tank. Physicochemical parameters, including temperature, pH, total dissolved solids (TDS), nitrate, and iron, together with microbiological indicators comprising heterotrophic plate count (HPC), total coliforms, and thermotolerant (fecal) coliforms, were analyzed using standard laboratory methods and compared with the Philippine National Standards for Drinking Water (PNSDW) and the World Health Organization (WHO) Guidelines for Drinking-water Quality. The results showed that pH, nitrate, and iron concentrations complied with both PNSDW and WHO standards, whereas TDS exceeded the PNSDW acceptable limit at two sampling sites. In contrast, microbiological analyses revealed elevated HPC in all samples, total coliforms at every sampling site, and fecal coliform contamination in water collected from the household storage and distribution system. These findings suggested that while groundwater chemistry remained generally acceptable, microbial contamination likely occurred during post-extraction storage and household distribution. The study concluded that untreated deep-well water was microbiologically unsuitable for direct human consumption despite meeting most physicochemical standards. The findings highlighted the need for routine groundwater monitoring, improved well protection, proper storage and distribution infrastructure, and household water treatment to reduce waterborne disease risks and support integrated groundwater quality management in flood-prone rural communities.

KEYWORDS: Groundwater quality; drinking water; deep well; physicochemical analysis; microbiological contamination; public health; Philippines

1. Introduction

Safe drinking water is fundamental to human health, socioeconomic development, and environmental sustainability. Access to safe and affordable drinking water has been recognized as one of the principal targets of the United Nations Sustainable Development Goal (SDG) 6, which seeks to ensure universal and equitable access to safe drinking water by 2030. Despite global progress in improving water accessibility, the WHO and the United Nations Children's Fund (UNICEF) estimate that approximately 2 billion people worldwide continue to consume drinking water contaminated with fecal matter, exposing millions to preventable waterborne diseases, including diarrhea, cholera, dysentery, typhoid fever, and hepatitis A [1]. Groundwater provides approximately half of the water withdrawn for domestic use worldwide and serves as the primary source of drinking water for most rural populations [2]. Owing to natural filtration through soil and geological formations, groundwater has traditionally been regarded as a relatively safe source of drinking water. However, increasing evidence has demonstrated that groundwater quality is vulnerable to contamination arising from agricultural intensification, inadequate sanitation infrastructure, poorly constructed septic systems, land-use changes, urbanization, and climate-induced flooding [3,4]. Consequently, the long-held assumption that untreated groundwater is inherently safe for human consumption has been increasingly challenged.

In the Philippines, deep wells remain the principal source of drinking water for many rural households because centralized piped water systems are either unavailable or economically inaccessible. Although groundwater generally exhibits favorable physicochemical characteristics, previous investigations conducted in different regions of the country have consistently reported microbiological contamination exceeding national drinking water standards [5]. These findings indicate that groundwater safety should not be evaluated solely based on physicochemical characteristics because microbial contamination may occur during groundwater abstraction, storage, or household distribution. Water quality assessment therefore requires complementary evaluation of physicochemical parameters, including temperature, pH, TDS, nitrate, and iron, together with microbiological indicators such as HPC, total coliforms, and thermotolerant (fecal) coliforms. Physicochemical parameters describe hydrogeochemical conditions and potential anthropogenic influences, whereas microbiological indicators provide internationally accepted evidence of sanitary integrity and possible fecal contamination because direct detection of all waterborne pathogens is technically impractical [6, 7].

Recent international studies have further demonstrated that groundwater quality has become increasingly influenced by climate variability, flooding, rapid population growth, and deteriorating sanitation infrastructure. Groundwater vulnerability has increased substantially in many low- and middle-income countries because of rapid urbanization and changing hydrological conditions [4]. Likewise, groundwater quality deterioration across Asia has been associated with intensive agricultural activities and ineffective waste management systems [3]. Similar conditions have been reported in flood-prone communities in the Philippines, where groundwater quality may deteriorate because of seasonal runoff, inadequate sanitation facilities, and poor post-extraction water handling practices [8]. These findings emphasize that drinking water quality should be evaluated throughout the entire water supply chain rather than solely at the groundwater source.

This perspective is supported by internationally recognized drinking water quality frameworks. The Source-to-Tap Framework recognizes that water quality may be affected at every stage of the supply chain, from groundwater recharge and extraction to storage, distribution, and household handling. Complementing this concept, the Multiple Barrier Approach emphasizes that safe drinking water depends on several protective barriers, including source protection, well construction, treatment, storage, distribution, and continuous monitoring, and that failure of any single barrier may permit contamination despite satisfactory physicochemical conditions [6]. Furthermore, the Indicator Organism Concept recommends using heterotrophic plate count, total coliforms, and thermotolerant (fecal) coliforms as practical indicators of microbial water quality because direct detection of all pathogenic microorganisms is technically difficult and economically impractical [7, 8]. Together, these frameworks provide the scientific basis for integrating physicochemical and microbiological analyses when evaluating groundwater suitability for domestic use.

Based on these concepts, the present study adopted the conceptual framework illustrated in Figure 1, which demonstrates that groundwater quality is determined by two complementary dimensions: physicochemical characteristics and microbiological quality indicators. Physicochemical parameters including temperature, pH, total dissolved solids, nitrate, and iron, describe the hydrochemical condition of groundwater, whereas microbiological indicators including heterotrophic plate count, total coliforms, and thermotolerant (fecal) coliforms, reflect the sanitary integrity of the water supply and potential contamination by pathogenic microorganisms. Laboratory results were evaluated according to the PNSDW [10] and the WHO Guidelines for Drinking-water Quality [6] to determine groundwater suitability for domestic consumption. The framework further recognizes that even when groundwater satisfies physicochemical standards, post-extraction contamination during storage and household distribution may compromise microbiological safety and increase public health risks.

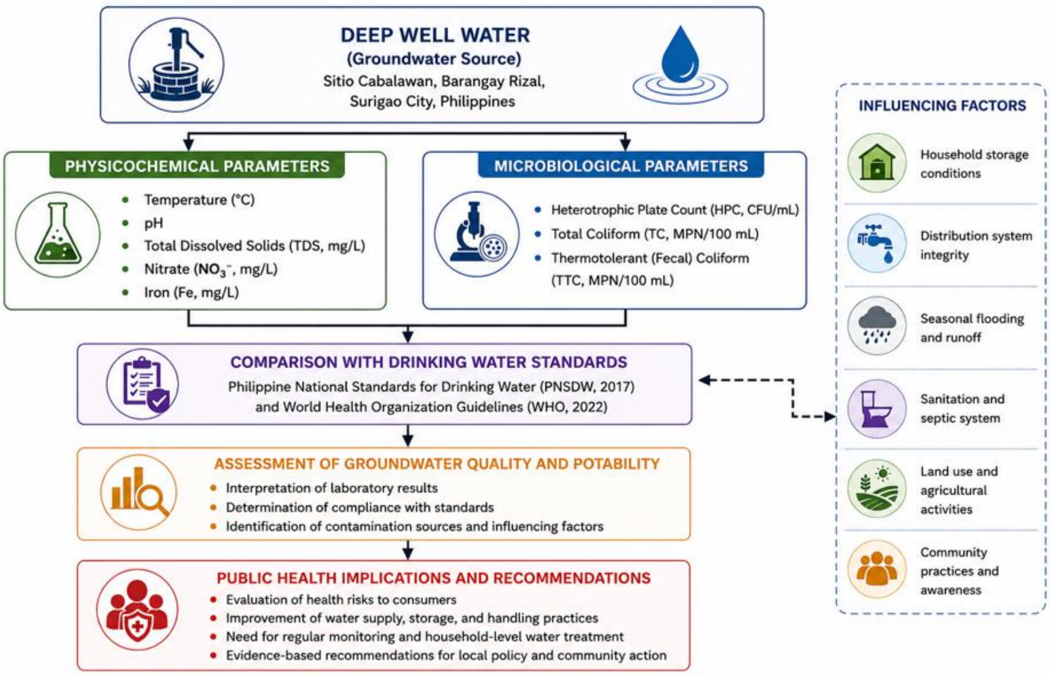

Figure 1. Conceptual Framework of the Study.

The framework illustrates the relationships among groundwater physicochemical characteristics, microbiological quality indicators, drinking water standards, groundwater suitability assessment, and public health implications. Sitio Cabalawan, Barangay Rizal, Surigao City, represents a typical flood-prone rural community where residents rely almost exclusively on untreated deep-well water for drinking, cooking, and other domestic purposes. Despite this dependence, no comprehensive assessment has simultaneously evaluated both the physicochemical and microbiological quality of groundwater supplied through different household water configurations. Previous studies have primarily focused on either physicochemical characteristics or microbiological contamination and have generally evaluated groundwater only at the source, with limited consideration of communal hand pumps, household hand pumps, and elevated household storage systems. Moreover, the contribution of post-extraction storage and household distribution to microbiological deterioration has received relatively little attention in rural groundwater studies.

To address these knowledge gaps, this study evaluated the physicochemical and microbiological quality of untreated deep-well water used for domestic purposes in Sitio Cabalawan, Barangay Rizal, Surigao City, Philippines. Specifically, the study determined the physicochemical characteristics of groundwater, including temperature, pH, total dissolved solids, nitrate, and iron concentrations; assessed microbiological quality based on heterotrophic plate count, total coliforms, and thermotolerant (fecal) coliforms; compared the analytical results with the PNSDW and the WHO Guidelines for Drinking-water Quality; and evaluated the suitability of untreated groundwater for domestic use and its implications for public health and groundwater management. By integrating physicochemical and microbiological analyses across multiple household water supply configurations, this study extends previous groundwater quality assessments beyond source-water evaluation and provides localized evidence supporting source-to-tap groundwater quality management in flood-prone rural communities.

This integrated approach also represents the principal novelty of the study. Unlike many previous investigations that assessed either physicochemical characteristics or microbiological contamination independently, or evaluated groundwater only at the point of abstraction, the present study simultaneously examined both dimensions across three representative household water supply configurations, communal hand pumps, household hand pumps, and household faucets supplied through elevated storage tanks. By demonstrating that microbiological deterioration may occur after groundwater extraction despite generally acceptable physicochemical quality, the study provides practical evidence supporting comprehensive groundwater monitoring and improved rural drinking water management.

2. Materials and Methods

3.1. Study Area and Research Design.

This study was conducted in Sitio Cabalawan, Barangay Rizal, Surigao City, Surigao del Norte, Philippines, a rural community located at approximately 9°47′16.6″ N and 125°28′33.4″ E. The study area is situated approximately 1.90 km from Barangay San Juan and 1.62 km from Barangay Sabang. According to the Department of Environment and Natural Resources (DENR), the area is classified as timberland and is characterized by low-lying terrain, swampy areas, and seasonal flooding during periods of heavy rainfall. As illustrated in Figure 2, residents rely primarily on untreated groundwater extracted from privately owned and communal deep wells because the community is not connected to the municipal water distribution system. The combination of poor drainage, seasonal flooding, and decentralized groundwater use potentially increases groundwater vulnerability to contamination from surface runoff, septic systems, and other environmental sources.

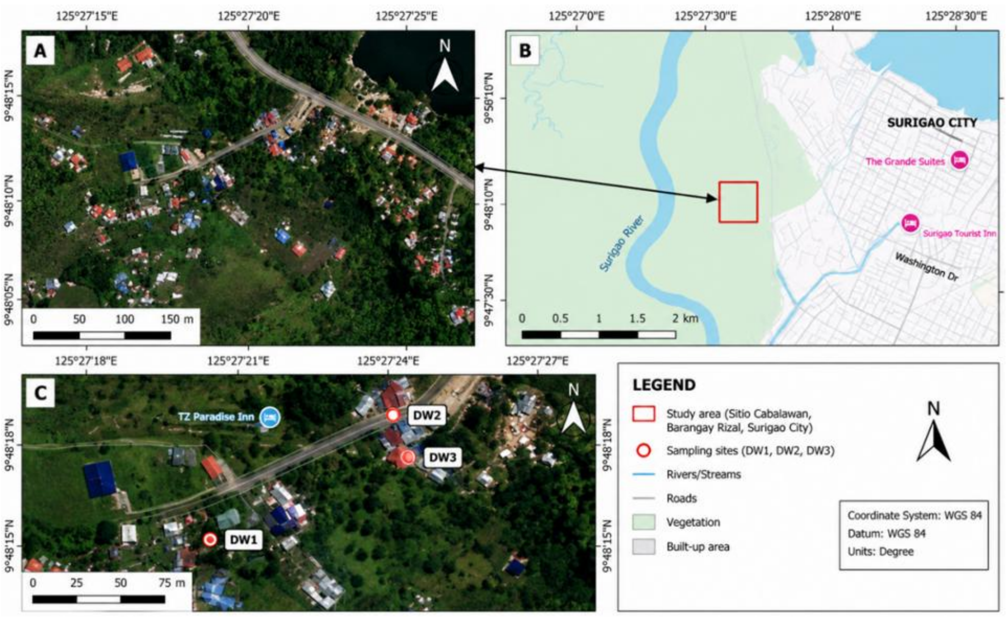

Figure 2. Study area and groundwater sampling locations in Sitio Cabalawan, Barangay Rizal, Surigao City, Philippines. (A) Regional location of the study area within Surigao City. (B) Location of Sitio Cabalawan relative to the Surigao River. (C) High-resolution satellite image showing the three deep well sampling sites (DW1–DW3) used for physicochemical and microbiological analyses. The map includes the study area boundary, road network, north arrow, scale bar, and coordinate reference (WGS 84).

This study employed a descriptive cross-sectional research design to evaluate the physicochemical and microbiological quality of untreated deep-well water used for domestic purposes. A descriptive approach was considered appropriate because the study aimed to characterize existing groundwater quality without manipulating environmental conditions. Laboratory results were subsequently compared with the PNSDW [10] and the WHO Guidelines for Drinking-water Quality [6] to determine compliance with established drinking water quality standards.

3.2. Sampling Design and Water Sample Collection.

A purposive sampling strategy was adopted to select groundwater sources representing the principal household water supply configurations used in Sitio Cabalawan. Three representative sampling sites were identified: Deep Well 1 (DW1), a communal hand pump representing a shared community groundwater source; Deep Well 2 (DW2), a household hand pump representing direct household groundwater extraction; and Deep Well 3 (DW3), a household faucet supplied through an elevated storage tank representing household storage and distribution systems. These sampling sites were selected to evaluate the influence of different water abstraction, storage, and distribution practices on groundwater quality, particularly the potential for microbiological contamination after groundwater extraction. Water samples were collected following the procedures described in the Standard Methods for the Examination of

Water and Wastewater [11] and the WHO Guidelines for Drinking-water Quality [6]. Prior to sampling, faucet attachments and hose extensions were removed to minimize external contamination. Water outlets were disinfected using 70% ethanol and flushed continuously for approximately three minutes to remove stagnant water and obtain representative groundwater samples [11]. The sampling procedures and representative groundwater supply systems are presented in Figure 3.

Figure 3. Groundwater sampling sites and water sample collection procedures. (A–C) The three deep well sampling sites (DW1, DW2, and DW3) selected for physicochemical and microbiological analyses. (D–F) Preparation of the sampling outlets before water collection, including removal of the cloth filter, outlet sanitization with 70% alcohol, and flushing for approximately three minutes to remove stagnant water and reduce the risk of sample contamination. (G) Sterile 100-mL sampling bottles and an insulated cooler used for the preservation and transport of water samples to the microbiology laboratory.

Microbiological samples were aseptically collected using sterile 100-mL sampling bottles, whereas physicochemical samples were collected in clean 500-mL high-density polyethylene (HDPE) containers. All containers were labeled with the sampling site, date, and time of collection to ensure sample traceability [11]. Immediately after collection, the samples were transported in insulated coolers containing ice packs and maintained at approximately 4 °C to preserve sample integrity and minimize physicochemical and microbiological changes before laboratory analysis [6, 11]. Microbiological analyses were conducted at the Water Bacteriology Laboratory of Caraga Regional Hospital, whereas physicochemical analyses were performed at Cotecna Elite Philippines Laboratory, an accredited analytical laboratory, using standardized analytical methods.

3.5. Physicochemical Analysis.

Physicochemical analyses were conducted using internationally recognized analytical procedures prescribed in the Standard Methods for the Examination of Water and Wastewater [11]. The physicochemical parameters evaluated in this study and their corresponding drinking water standards are summarized in Table 1. Water temperature was measured immediately after sample collection using a calibrated thermometer. The pH was determined using the electrometric method (APHA Method 4500-H^+ B), whereas TDS were measured using APHA Method 2540 C [11]. Nitrate concentration was determined using the colorimetric method based on U.S. EPA Method 352.2, which is widely applied for nitrate determination in drinking water (U.S. Environmental Protection Agency [EPA], 1993). Iron concentration was measured using Inductively Coupled Plasma–Atomic Emission Spectroscopy (ICP–AES) following APHA Method 3120 B [11].All laboratory instruments were calibrated according to the manufacturers' specifications prior to analysis to ensure analytical accuracy, precision, and reliability.

Table 1. Physicochemical Parameters Evaluated.

Parameter	Unit	Drinking Water Standard
Temperature	°C	Reference value*
pH	pH units	6.5–8.5
Total Dissolved Solids	mg/L	≤ 500 (PNSDW)
Nitrate	mg/L	≤ 50
Iron	mg/L	≤ 1.0

*Temperature has no health-based guideline value but was measured because it influences physicochemical characteristics, microbial activity, and the overall quality of drinking water.

3.6. Microbiological Analysis.

Microbiological quality was evaluated using three internationally recognized indicator organisms for drinking water assessment: HPC, expressed as colony-forming units per milliliter (CFU/mL); total coliforms (TC), expressed as the most probable number per 100 mL (MPN/100 mL); and thermotolerant (fecal) coliforms (TTC), also expressed as MPN/100 mL [6]. HPC was determined using the Pour Plate Method, whereas total coliforms and thermotolerant coliforms were quantified using the Multiple Tube Fermentation Technique, also known as the Most Probable Number (MPN) method, following the procedures described in the Standard Methods for the Examination of Water and Wastewater [11]. All microbiological analyses were conducted at the Water Bacteriology Laboratory of Caraga Regional Hospital using standardized laboratory procedures. The results were interpreted according to the microbiological criteria specified in the PNSDW [10].

3.7. Quality Assurance and Quality Control.

Quality assurance and quality control (QA/QC) procedures were implemented throughout sample collection, transportation, laboratory analysis, and data processing to ensure the accuracy and reliability of the analytical results. Sterile sampling bottles were used for microbiological analyses to prevent cross-contamination. All samples were transported under refrigerated conditions (approximately 4 °C) and analyzed within the recommended holding times specified in the Standard Methods for the Examination of Water and Wastewater [11]. Laboratory instruments were routinely calibrated before analysis, and all measurements were performed following standardized analytical protocols by accredited laboratories. Sample labels, laboratory records, and analytical data were independently verified before data analysis to minimize transcription and reporting errors.

3.8. Data Analysis.

Analytical results were summarized using descriptive statistics. Physicochemical parameters were presented as measured values for each sampling site, whereas microbiological results were expressed as colony-forming units per milliliter (CFU/mL) and most probable number per 100 mL (MPN/100 mL), as appropriate. Measured values were compared with the maximum acceptable limits specified in the PNSDW [10] and the WHO Guidelines for Drinking-water Quality [6] to determine compliance with drinking water quality standards. The results were subsequently interpreted to evaluate the suitability of untreated groundwater for domestic use and to identify potential sources of contamination associated with different household water supply configurations.

3.9. Ethical Considerations.

Permission to collect groundwater samples was obtained from household owners and community representatives before field sampling. The study involved only environmental water samples and did not include human participants, clinical specimens, or personally identifiable information. Therefore, formal institutional ethics approval was not required. All sampling activities were conducted with respect for community property and in accordance with accepted environmental research practices. The analytical methods used for each physicochemical and microbiological parameter are summarized in Table 2.

Table 2. Summary of Analytical Methods.

Parameter	Analytical Method	Standard Reference
Temperature	Calibrated thermometer	APHA (2023)
pH	APHA Method 4500-H^+ B	APHA (2023)
Total Dissolved Solids	APHA Method 2540 C	APHA (2023)
Nitrate	U.S. EPA Method 352.2	U.S. EPA (1993)
Iron	APHA Method 3120 B (ICP–AES)	APHA (2023)
Heterotrophic Plate Count	Pour Plate Method	APHA (2023)
Total Coliforms	Multiple Tube Fermentation (MPN)	APHA (2023)
Thermotolerant (Fecal) Coliforms	Multiple Tube Fermentation (MPN)	APHA (2023)

3. Results and Discussion

4.1 Physicochemical Characteristics of Groundwater

The physicochemical characteristics of groundwater samples collected from the three deep wells are summarized in Table 3. The evaluated parameters included pH, TDS, nitrate, and iron, which are commonly used to assess the chemical suitability of groundwater for domestic consumption. The measured pH values ranged from 7.55 to 7.86, indicating that all groundwater samples were slightly alkaline. Nevertheless, all values remained within the acceptable range of 6.5–8.5 specified by both the PNSDW and the WHO. These findings suggest that the groundwater exhibited a stable acid–base balance and was unlikely to cause corrosion, scaling, or adverse effects on water palatability.

Table 3. Physicochemical characteristics of groundwater samples collected from the three deep wells in Sitio Cabalawan, Barangay Rizal, Surigao City, compared with the PNSDW and the WHO guidelines.

Parameter	**Unit**	**DW1**	**DW2**	**DW3**	**PNSDW (2017)**	**WHO (2022)**	**Interpretation**
pH	SU	7.55	7.74	7.86	6.5–8.5	6.5–8.5	All samples complied
Total Dissolved Solids	mg/L	794	562	747	600*	≤1000†	DW1 and DW3 exceeded PNSDW; all below WHO aesthetic threshold
Nitrate (as NO_3-N)	mg/L	<0.0209	<0.0209	0.0641	50	50	All samples complied
Iron	mg/L	0.234	0.141	0.0499	1.0	0.3	All samples complied

* PNSDW. †WHO considers TDS mainly an aesthetic parameter; water above approximately 1000 mg/L may become less acceptable in taste.

As shown in Table 3, TDS concentrations ranged from 562 to 794 mg/L. Deep Well 2 exhibited the lowest TDS concentration (562 mg/L), whereas Deep Wells 1 (794 mg/L) and 3 (747 mg/L) exceeded the PNSDW aesthetic guideline of 600 mg/L. However, all measured values remained below the WHO aesthetic threshold of approximately 1000 mg/L. Elevated TDS concentrations generally reflect the dissolution of naturally occurring minerals within aquifer materials and may influence the taste and acceptability of drinking water without necessarily posing a direct health risk. Nitrate concentrations were consistently low across all sampling sites. Concentrations in Deep Wells 1 and 2 were below the analytical detection limit (<0.0209 mg/L), whereas Deep Well 3 contained only 0.0641 mg/L. These values were substantially lower than the regulatory limit of 50 mg/L, indicating minimal contamination from agricultural runoff, domestic wastewater, or septic system leakage. Similarly, dissolved iron concentrations ranged from 0.0499 to 0.234 mg/L, remaining below both the WHO aesthetic guideline (0.3 mg/L) and the PNSDW limit (1.0 mg/L). These results indicate that dissolved iron is unlikely to impair water quality through staining, discoloration, metallic taste, or biofilm formation within the study area. Overall, the physicochemical assessment demonstrated that groundwater from the three sampling sites exhibited generally acceptable chemical quality. The only parameter that exceeded the national guideline was TDS in Deep Wells 1 and 3, suggesting relatively high mineralization but not necessarily indicating a health risk.

4.2. Microbiological Characteristics of Groundwater.

The microbiological characteristics of groundwater samples obtained from the three deep wells are presented in Table 4. Microbiological quality was evaluated using HPC, total coliforms, and thermotolerant (fecal) coliforms, which are internationally recognized indicators of drinking water safety. As shown in Table 4, all groundwater samples exhibited heterotrophic plate counts exceeding 5600 CFU/mL, substantially higher than the Philippine standard of 500 CFU/mL. Elevated HPC values indicate abundant heterotrophic bacterial populations and suggest favorable environmental conditions for microbial growth within groundwater systems or household water storage and distribution components. Although HPC organisms are not necessarily pathogenic, high bacterial counts may indicate inadequate sanitary conditions and increase the likelihood of microbial regrowth.

Table 4. Microbiological characteristics of groundwater samples collected from the three deep wells based on duplicate laboratory analyses.

Parameter	Unit	DW1 (Mean)	DW2 (Mean)	DW3 (Mean)	PNSDW (2017)	Interpretation
HPC	CFU/mL	>5600	>5600	>5600	<500	All exceeded the standard
Total Coliform	MPN/100 mL	3.6	>8.0	>8.0	<1.1	All exceeded the standard
Thermotolerant (Fecal) Coliform	MPN/100 mL	<1.1	0.55*	8.0	<1.1	DW3 exceeded the standard

*Mean of duplicate measurements (<1.1 and 1.1 MPN/100 mL). Source: Caraga Regional Hospital, Department of Pathology–Anatomic and Clinical Laboratory.

Total coliform bacteria were detected in all sampling sites. Deep Well 1 recorded a mean concentration of 3.6 MPN/100 mL, whereas Deep Wells 2 and 3 consistently exceeded 8.0 MPN/100 mL. All measured values exceeded the PNSDW limit of <1.1 MPN/100 mL, indicating deficiencies in source protection or contamination during groundwater abstraction, storage, or household distribution. Thermotolerant (fecal) coliforms were not detected in Deep Well 1 and were detected only at a very low concentration in Deep Well 2 (mean = 0.55 MPN/100 mL). In contrast, Deep Well 3 exhibited a mean concentration of 8.0 MPN/100 mL, substantially exceeding the regulatory standard. The presence of fecal coliforms strongly suggests contamination from human or animal waste and indicates that groundwater supplied through the household storage and distribution system was microbiologically unsafe for direct consumption without treatment. Although the physicochemical quality of groundwater was generally satisfactory, the microbiological assessment revealed widespread contamination across the study area. These findings demonstrate that acceptable chemical quality does not necessarily guarantee microbiological safety, highlighting the importance of routine microbial monitoring, improved sanitary protection of groundwater sources, regular maintenance of household storage systems, and appropriate household water treatment before consumption [12–15].

4.3. Overall Compliance with Drinking Water Standards.

The overall compliance of groundwater samples with the PNSDW 2017 is summarized in Table 5. As summarized in Table 5, all three groundwater sources complied with the prescribed limits for pH, nitrate, and iron, indicating generally acceptable physicochemical quality. However, Deep Wells 1 and 3 exceeded the recommended limit for total dissolved solids, suggesting elevated mineral content that may reduce the aesthetic quality of the water. In contrast, microbiological quality was unsatisfactory at all sampling sites. Heterotrophic plate counts exceeded the allowable limit in every groundwater sample, and total coliform bacteria were detected at concentrations above the regulatory standard in all three wells. Thermotolerant (fecal) coliforms were absent in Deep Well 1, borderline in Deep Well 2, and exceeded the permissible limit in Deep Well 3, indicating probable fecal contamination associated with the household storage and distribution system. Collectively, these findings indicate that none of the sampled groundwater sources fully complied with the PNSDW requirements for potable water. Although most physicochemical parameters satisfied drinking water standards, microbiological contamination represented the principal limitation to groundwater safety. Consequently, untreated groundwater from the three deep wells is not recommended for direct human consumption. Appropriate treatment measures, including boiling, chlorination, filtration, or ultraviolet disinfection, together with improved wellhead protection, sanitary storage facilities, and routine monitoring, should be implemented to safeguard public health.

Table 5. Compliance of physicochemical and microbiological parameters of deep-well water with the PNSDW.

Parameter	Standard (PNSDW, 2017)	DW1	DW2	DW3
Physicochemical Parameters				
pH	6.5–8.5	Pass	Pass	Pass
TDS (mg/L)	≤600	Fail	Pass	Fail
Nitrate (mg/L)	≤50	Pass	Pass	Pass
Iron (mg/L)	≤1.0	Pass	Pass	Pass
Microbiological Parameters				
HPC (CFU/mL)	<500	Fail	Fail	Fail
Total Coliform (MPN/100 mL)	<1.1	Fail	Fail	Fail
Thermotolerant (Fecal) Coliform (MPN/100 mL)	<1.1	Pass	Borderline*	Fail
Overall Water Quality Assessment				
Physicochemical Quality	All physicochemical parameters within standards	Acceptable except TDS	Acceptable	Acceptable except TDS
Microbiological Quality	All microbiological parameters within standards	Unsatisfactory	Unsatisfactory	Unsatisfactory
Suitability for Direct Drinking	Compliance with all PNSDW parameters	Not Recommended	Not Recommended	Not Recommended

4.4. Descriptive Statistical Analysis.

Descriptive statistics were used to summarize the physicochemical and microbiological characteristics of groundwater samples collected from the three deep wells. Physicochemical parameters were reported as laboratory-measured values for each sampling site because only one measurement was obtained for each parameter. For microbiological analyses, duplicate laboratory measurements were summarized using arithmetic means while individual observations were also considered during interpretation. Measured values were compared with the PNSDW [10] and the WHO Guidelines for Drinking-water Quality [6] to evaluate compliance with drinking water quality standards. Because the study included only three sampling sites and limited replicate measurements, inferential statistical analyses, such as *t*-tests or analysis of variance (ANOVA), were not appropriate. Therefore, the interpretation focused on descriptive comparisons and regulatory compliance, providing an evidence-based assessment of groundwater suitability for domestic use.

4. Conclusions

The present study demonstrated that untreated deep-well water in Sitio Cabalawan, Barangay Rizal, Surigao City generally exhibited acceptable physicochemical quality, with pH, nitrate, and iron concentrations complying with the PNSDW and the WHO guidelines. However, elevated TDS were observed at two of the three sampling sites. More importantly, microbiological analyses revealed elevated heterotrophic plate counts and the presence of total coliforms in all deep wells, while thermotolerant (fecal) coliforms were detected in the household storage and distribution system. These findings indicate that although the groundwater source is chemically suitable, its microbiological quality has been compromised, rendering the untreated water unsuitable for direct human consumption. The findings underscore the need for routine groundwater quality monitoring and improved sanitary management of wells, household storage tanks, and water distribution systems within the community. Strengthening source protection, maintaining storage and distribution infrastructure, and promoting appropriate household water treatment practices can help reduce the risk of waterborne diseases and improve the safety of drinking water supplies. This study provides baseline scientific evidence that may assist local government units and public health authorities in developing evidence-based, community-level strategies for the sustainable management of groundwater resources and the protection of public health, particularly in flood-prone rural communities.

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Conflict of Interest

The author declares no conflict of interest.

Author Contributions

The author solely conceived and designed the study; conducted the field sampling; performed data collection, analysis, and interpretation; drafted and revised the manuscript; and approved the final version of the manuscript.

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