Annals of Tropical Research 47 (2):32-59(2025)
https://doi.org/10.32945/atr4724.2025

Original Article

Assessment of the Water Quality in Selected Groundwater Wells in the Central District of Baybay City, Leyte, Philippines

Bryan D. Garay[1] and Ma. Grace C. Sumaria[1,2*]

ABSTRACT

Groundwater serves as a vital water resource for domestic uses in the Central District of Baybay City. This study evaluated the impact of septic tank systems on the quality of groundwater analyzed from a selection of 14 wells located in Baybay City's Central District, covering 943 households across Zones 20, 22, and 23. A total of 88 septic tanks were found within the 25-meter buffer zone surrounding the wells, violating the minimum distance requirement specified in the Philippine Sanitation Code. Water samples from 14 wells were analyzed for pH, temperature, dissolved oxygen, total dissolved solids, electrical conductivity, salinity, and nitrate. Results showed that the nitrate concentrations were within safe limits, ranging from 0.02 to 0.39mg L^{-1}, but spatially clustered, indicating localized contamination risks. pH levels ranged from 7.19 to 8.98, with two wells exceeding WHO standards. Temperature values (26.90°C to 37.80°C) surpassed the PNSDW's acceptable range, potentially promoting microbial growth. Dissolved oxygen levels averaged 2.43mg L^{-1}, while 64.29% of wells exceeded the electrical conductivity limit of 1500μS cm^{-1}. Total dissolved solids ranged from 253 to 1,329mg L^{-1}, with only one well meeting the ideal taste threshold. Salinity reached up to 1,350mg L^{-1} in some wells, exceeding the desirable limit recommended by the WHO.

Received: 2 February 2025
Revised: 11 July 2025
Accepted: 2 August 2025
Published: 12 December 2025

Keywords: groundwater quality, groundwater wells, PNSDW, spatial distribution

[1]Department of Agricultural and Biosystems Engineering, Visayas State University, Baybay City, Leyte, 6521, Philippines
[2]Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Selangor, Malaysia

*Corresponding Author. Address: Department of Agricultural and Biosystems Engineering, Visayas State University, Baybay City, Leyte, 6521, Philippines; Email: grace.sumaria@vsu.edu.ph and garaybryan6420@gmail.com

INTRODUCTION

Groundwater serves as the primary source of freshwater for the global population, supporting domestic use, food production, and industrial activities. In regions where surface water is unavailable or too expensive to access, approximately one-third of the world's population relies on groundwater as their primary source of drinking water (Al-Hashimi et al., 2021).

Groundwater plays a crucial role in supplying drinking water across Southeast Asia and the Pacific. In countries like Timor-Leste, Indonesia, and Kiribati, up to 90% of urban households rely on groundwater. Most groundwater is accessed through wells and springs, although piped systems exist in places such as Timor-Leste and Vietnam (Carrard et al., 2019). Globally, groundwater is equally vital providing drinking water to about 50% of the population in both the United States and the Philippines (US EPA, 2017b; Elazegui, 2018). In arid countries such as Pakistan, Saudi Arabia, and Syria, around 90% of groundwater use is dedicated to irrigation (Elazegui, 2018).

In the Philippines, according to the national data from the National Water Resources Board, since 2002, the domestic sector consumes 49% of groundwater, with the remainder shared among agriculture (32%), industry (15%), and other sectors (4%). Approximately 60% of groundwater extraction occurs without water-right permits, resulting in indiscriminate withdrawal; meanwhile, a high percentage (86%) of piped-water supply systems rely on groundwater as a source (World Bank Group, 2003).

Water quality is a global concern, with the disposal of untreated wastewater posing a significant threat to human health. Approximately 80% of sewage from developed and emerging countries enters the environment untreated (Thomas, 2021; Sumaria, 2024).

Groundwater quality is influenced by natural and anthropogenic factors (Sheikhy Narany et al., 2014), with nitrate emerging as one of the most widespread and concerning contaminants. In the ASEAN region, nitrate pollution is a growing issue, particularly in areas of intensive agriculture where the excessive use of nitrogen fertilizers leads to the contamination of artesian wells used for drinking water. Beyond agricultural zones, nitrogen runoff can also trigger harmful algal blooms and the degradation of aquatic ecosystems, including coral reefs and fish populations. Elevated nitrate levels in drinking water pose serious health risks, particularly for children (Tirado, 2007).

This study focuses on the Central (*Poblacion)* District of Baybay City, Leyte, a rapidly developing area facing increased water demand. Despite its significance, no assessment of groundwater nitrate concentration has been conducted in this district, emphasizing the need for ongoing evaluations to ensure sustainable use for drinking, household needs, and agriculture. The aim was to characterize the spatial variation of groundwater quality, emphasizing nitrate concentration in the *Poblacion* District of Baybay City, Leyte.

MATERIALS AND METHODS

Sampling Area and Sampling Sites

Groundwater samples were collected from 14 wells located in Zones 20, 22, and 23 of Baybay City, Leyte, Philippines (Figure 1). These wells were selected to represent a range of domestic water sources, two of which (Z23-W011 and Z23-W07) are used for potable purposes such as cooking and drinking. Each well was geotagged using KoboCollect, an open-source mobile data collection application developed by KoboToolbox, enabling spatial referencing for subsequent GIS-based analysis (KoboToolbox, n.d.).

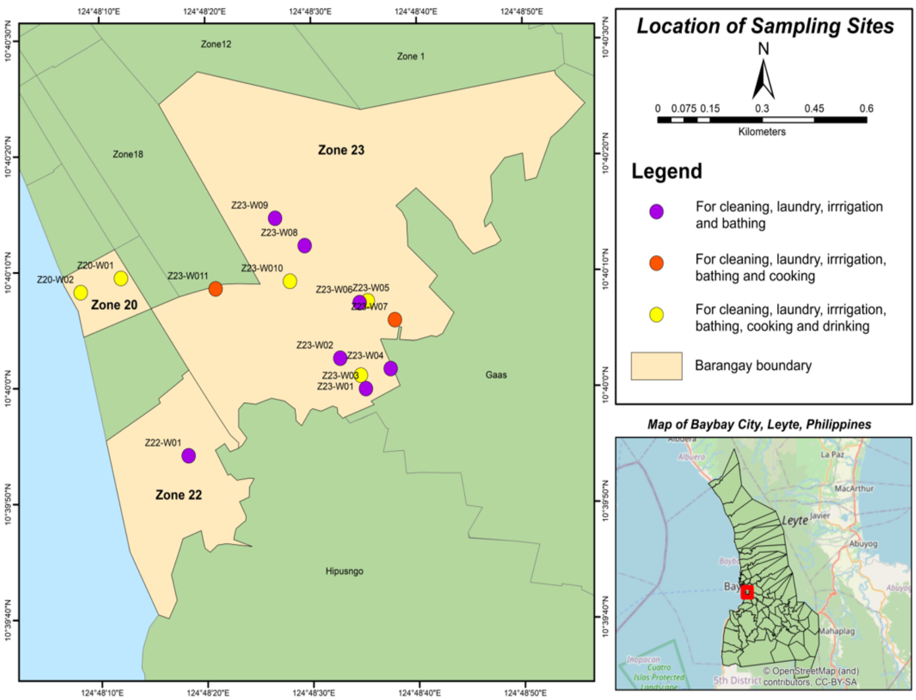

Figure 1. Map of the study site indicating groundwater sampling locations in the Central *(Poblacion)* District of Baybay City

Measurement of Physicochemical and Microbiological Parameters

Groundwater sampling was conducted in May 2023, during a period of average daily rainfall of 5.74mm, as recorded by the VSU-PAGASA Agrometeorological Station. In situ measurements of pH, temperature, total dissolved solids (TDS), dissolved oxygen (DO), electrical conductivity (EC), and salinity were carried out using a multimeter (Extech Instruments, USA) and a multiparameter water quality analyzer (Biobase Biodustry, Shandong, China). Nitrate concentrations were determined using the Ultraviolet Spectrophotometric Screening Method (Kelly &

Love, 2007), following standard analytical protocols. Total coliforms and thermotolerant (fecal) coliforms were assessed through the Multiple Tube Fermentation Technique (APHA, 1998) at PrimeWater Leyte Metro in Tacloban City, Leyte.

Geospatial Data Preparation and Analysis

Spatial data layers were developed to support the analysis of groundwater nitrate contamination. Building footprints and inferred septic tank locations were manually digitized from high-resolution satellite imagery in Google Earth, with supplementary data sourced from OpenStreetMap (OpenStreetMap contributors, 2023). Septic tank density was calculated using the Kernel Density tool in ArcGIS 10.6 Spatial Analyst, applying a 50 search radius to estimate the magnitude per unit area based on proximities to household locations (ESRI, 2011). The resulting raster surface depicted the spatial distribution of septic systems, following procedures from Murad and Khashoggi (2020) and Sumaria (2024). Household counts and coordinates were obtained from the Baybay City Local Government Unit.

Survey data and groundwater quality measurements were compiled in Microsoft Excel and spatialized via the Create XY Event Layer tool in ArcGIS to facilitate integration into the geodatabase. Figure 2 illustrates river flow direction in the study area, showing the possible contaminant pathways. The predominant water flow occurs from Zone 23 to Zone 22, with additional water flow observed in certain areas of Zone 1.

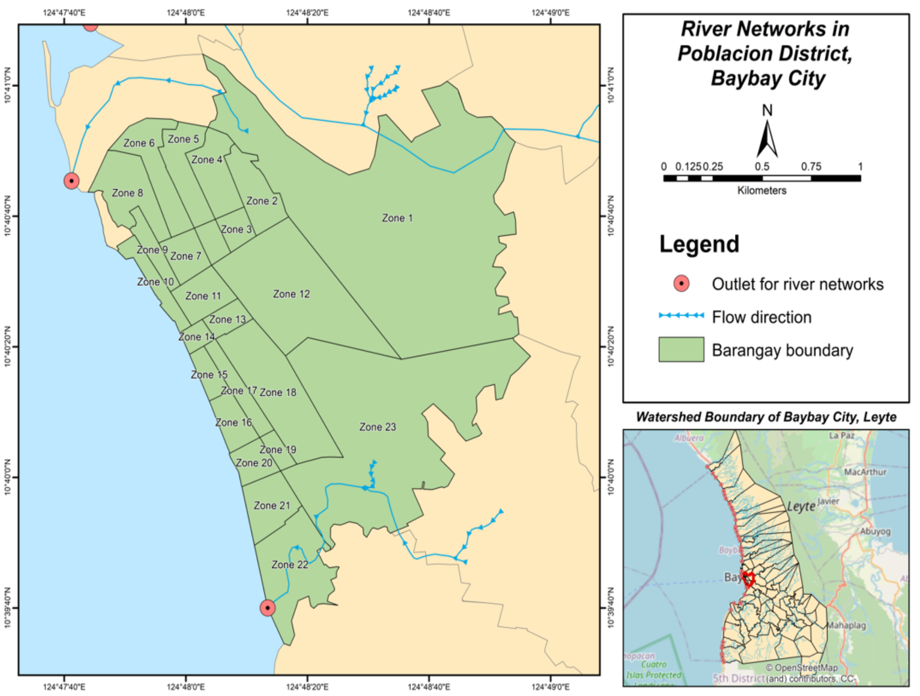

Figure 2. The digitized flow direction of river networks in the study area

Inverse Distance Weighting and Proximity Analysis. To estimate the spatial influence of septic tank proximity on nitrate concentrations, Inverse Distance Weighting (IDW) interpolation was conducted using the Spatial Analyst extension in ArcGIS. A 25m search radius was applied, and interpolation weights were calculated using the formula:

$$W_j = \sum_{i=1}^{n} \frac{1}{D_i} \quad [1]$$

$$D = \sqrt{(X_2 - X)^2 + (Y_2 - Y_1)^2} \quad [2]$$

Where:

W_J = inverse distance weight of a sampling well *j*
n = specific number of septic tanks within the buffer radius
D_i = distance from a well to a septic tank *i*
X and Y = spatial coordinates of the well and septic tank

To support the IDW procedure, the Point Distance tool in ArcGIS was used to compute pairwise Euclidean distances between wells and nearby septic tanks within the 25m buffer. The resulting proximity matrix was used for spatial correlation analyses (ESRI, n.d.).

The overall workflow, from septic tank mapping to proximity analysis and interpolation, was summarized in a schematic process diagram (Figure 3), which served as the framework for spatial data preparation and nitrate risk assessment.

Spatial Autocorrelation Analysis

Spatial autocorrelation was evaluated using Moran's I, a global indicator of spatial pattern that quantifies the degree of spatial clustering among values distributed across geographic space. This method is commonly applied in spatial statistics to detect non-random spatial patterns and is especially useful for identifying clustering in environmental variables (Lee, 2017; ESRI, n.d.).

In this study, Moran's I was used to assess the spatial distribution of nitrate concentrations and their potential correlation with the distance of wells from the coastline. The analysis was performed using data from seven wells with complete nitrate measurements, providing insights into the spatial structure and potential geographic drivers of groundwater contamination.

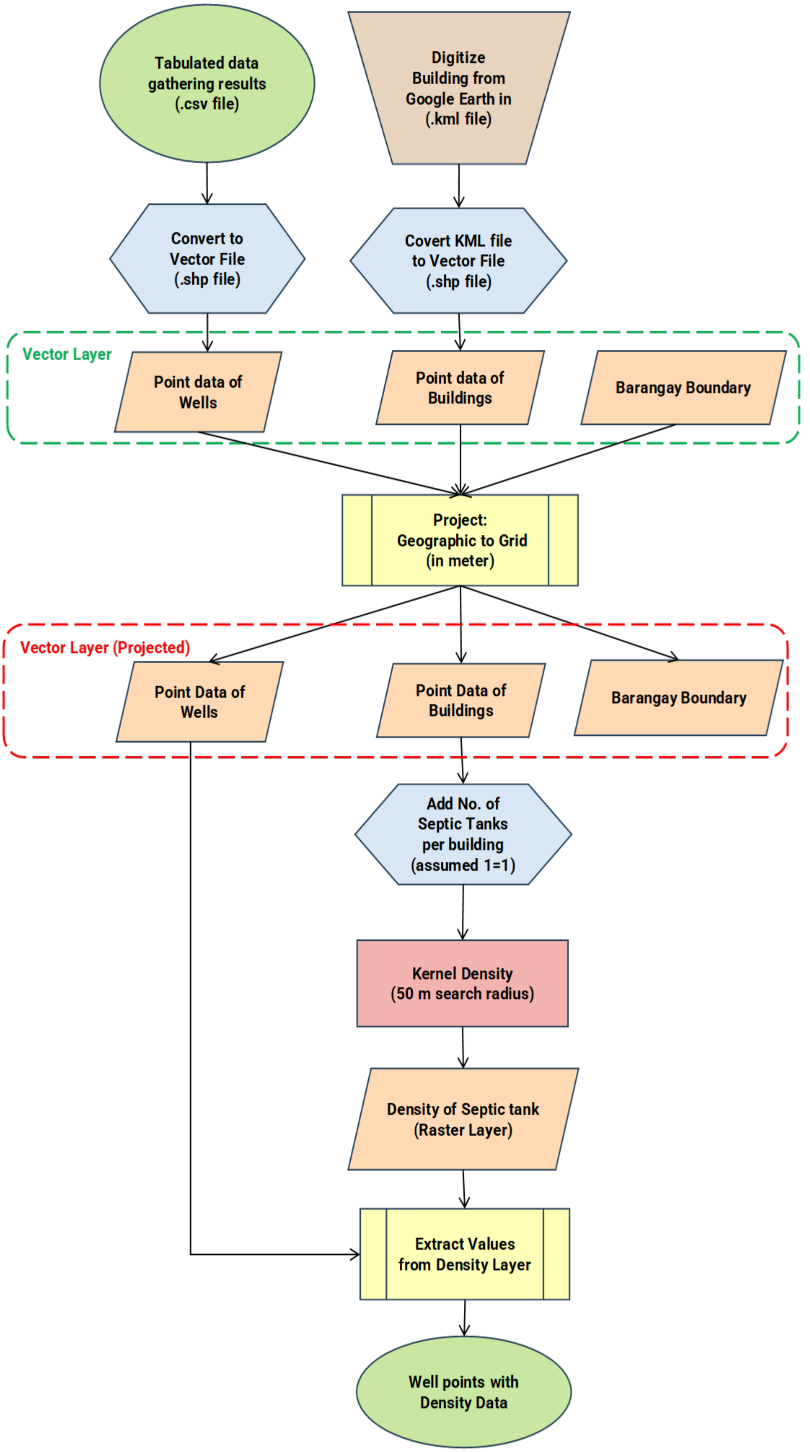

Figure 3. Workflow diagram illustrating the septic tank density analysis conducted using ArcGIS 10.8, adapted from Sumaria (2024).

RESULTS AND DISCUSSION

Septic Tank System

Anthropogenic sources, such as septic systems, contribute to groundwater contamination with nitrogen (Haller et al., 2013). In areas without sewage systems, septic systems play a crucial role in handling household wastewater disposal. These systems release the waste into an underground tank, which is then directed to an underground disposal field. During this process, nitrogen remains in the form of ammonium and organic compounds until it reaches the aerobic zone beneath the disposal field. Once it reaches this zone, the nitrogen oxidizes and transforms into nitrate. Subsequently, it is carried along with water and enters the groundwater. This pathway represents one of the significant mechanisms by which nitrogen from septic systems can contaminate groundwater (Zhou et al., 2015).

Baybay City, the second largest in Leyte and fourth in Eastern Visayas by land area, has 23 urban zones and 69 rural *barangays* (villages). Among these urban zones are Zones 20, 22, and 23 in the *Poblacion* or Central District. Zone 20 covers 3.95 hectares with 127 households and a population of 553. Zone 22 spans 4.97 hectares, housing 220 households and 1,050 residents. The largest among them, Zone 23, has a land area of 10.99 hectares, 596 households, and a population of 2,761 (City of Baybay, Leyte, 2024). Under the assumption that each household is equipped with one septic tank, the total number of septic tanks in these zones would be equivalent to the total number of households.

Septic tank failure is a serious issue especially in densely populated coastal areas like the *Poblacion*, Baybay City because it directly affects groundwater quality and public health. Failing septic systems can release untreated wastewater, containing pathogens, nutrients, and harmful substances, directly into groundwater or surface waters, posing a significant public health risk to individuals exposed to it. Drinking water from affected sources may become contaminated, necessitating filtration and disinfection, and excess nitrogen contamination can necessitate special treatment for drinking water systems. Additionally, chemicals discharged into septic systems, even in small quantities, can adversely affect water quality and public health in groundwater and surface water sources (US EPA, 2017a).

Chapter 17, Section 75 (c) of Presidential Decree 856, Code on Sanitation of the Philippines, issued in 1975, mandates that septic tanks be positioned at a minimum distance of 25m from any well, spring, cistern, or other drinking water supply source (Presidential Decree No. 856, S. 1975 | GOVPH, 1975). However, in the study area, it was observed that the actual distances between septic tanks and such water sources often deviated from this requirement, varying from 2 to 9m within a 10m buffer zone (Figure 4).

According to Philippine Department of Health (DOH) AO No. 2019-0047, the National Standard on the Design, Construction, Operation, and Maintenance of Septic Tank Systems, regular desludging every four years is required to preserve the septic tank's treatment efficiency. Additionally, inspections for cracks and ensuring proper baffle placement are necessary to prevent potential groundwater contamination from leakage.

Specifically, there were 88 septic tanks located within the 25m buffer zone at the study sites. Among these, 20 septic tanks were situated near Well 2 in Zone 20

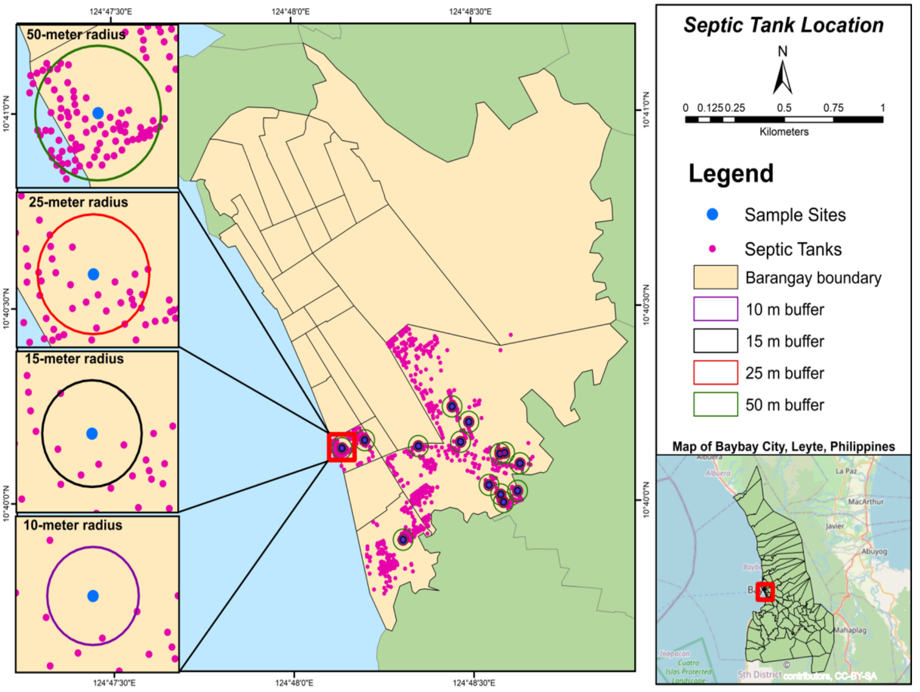

Figure 4. Septic tank location of the study site indicating the Z20-W02 well to septic tank distance with 50m, 25m, 15m and 10m search radius.

Spatial Variation of Water Quality in the Study Area

The spatial variability of water quality refers to differences in water quality characteristics across various locations within a specific study area. Understanding these variations at different temporal and spatial scales is crucial for effective surface water monitoring, allowing for the detection of both spatial and temporal changes in water quality. Regular monitoring is essential for identifying potential pollution sources (Sumaria, 2024).

In this study, seven parameters were examined to assess spatial variation. These parameters include pH, temperature, dissolved oxygen (DO), electrical conductivity (EC), salinity, total dissolved solids (TDS), and nitrate. Each parameter was analyzed to examine its distribution and variations across various locations.

Potential Hydrogen (pH). According to the World Health Organization (WHO, 2011), the optimal pH range for drinking water falls within the bracket of 6.5 to 8.5. Water outside the suggested pH range might contain harmful heavy metals, but that does not mean it is unsafe to drink—it just might not taste good (Butler, 2019). A bitter taste in the water and decreased effectiveness of chlorine disinfection occurs when the pH is high, prompting the necessity for added chlorine (DeZuane, 1997). During the sampling period, the pH levels in the sampled wells ranged from 7.21 to 8.95 (Figure 5). The pH map spans the central district, with IDW interpolation estimating values in unsampled barangays based on proximity to sampled wells. These are spatial estimates, not direct measurements (Khouni et al., 2021; Gong et al., 2014). Only two wells, such as Wells 10 and 11 in Poblacion Zone 23, exceed the maximum allowable limit for pH in drinking water. These wells had pH of 8.95 and 8.77, respectively. Water in these wells might taste bitter and hinder the body's absorption of vital minerals from elevated pH levels (APEC Water,

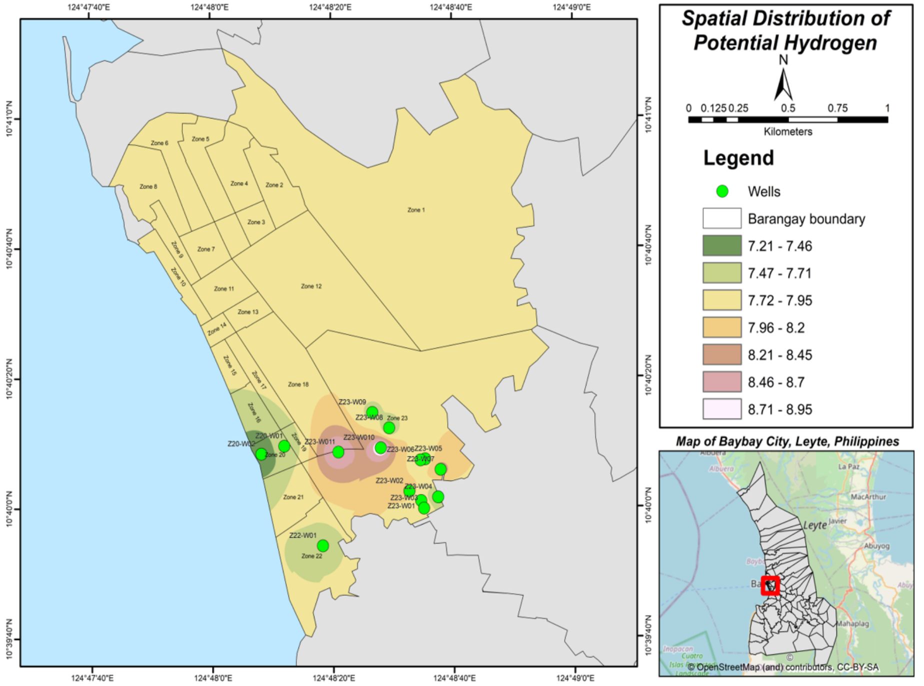

Figure 5. Spatial distribution of potential hydrogen (pH) in the study area

Temperature. Water quality is intricately linked to temperature, influencing diverse physical, chemical, and biological processes. These encompass the absorption of chemicals, the decay of chlorine (Monteiro et al., 2017), and processes related to microbial growth and competition (Prest et al., 2016). More specifically, temperature significantly shapes microorganisms' survival and growth conditions and modulates the kinetics of numerous chemical reactions (Ingerson-Mahar & Reid, 2013).

At elevated temperatures, water, especially groundwater, exhibits greater mineral solubility from the surrounding rock, leading to increased electrical conductivity. Conversely, higher temperatures reduce the solubility of gases like oxygen in water, resulting in lower dissolved oxygen levels compared to cooler water (Water Science School, 2018). This may have health implications for those relying on these water sources (WHO, 2006).

As the temperature of the water increases, there are more microorganisms in the water resulting in a higher demand for disinfection. This affects the water's taste, smell, and color, making it less suitable for consumption (Daniel et al., 2016). Elevated water temperatures can result in issues such as altered taste, unpleasant odor, unusual color, and corrosion.

Throughout the sampling period on May 24, 2023, the temperature of the water samples ranged from 27.21°C to 37.1°C (Figure 6). The highest temperature was recorded at Zone 23 Well 11 with an average temperature of 37.10°C.

As per the guidelines set by the Philippine National Standards for Drinking Water (PNSDW), the acceptable drinking water temperature range is from 10°C to 25°C. However, based on the measured temperature, it is evident that the recorded value exceeds the established standard limits. These wells might be susceptible to higher microbial growth and reduced palatability.

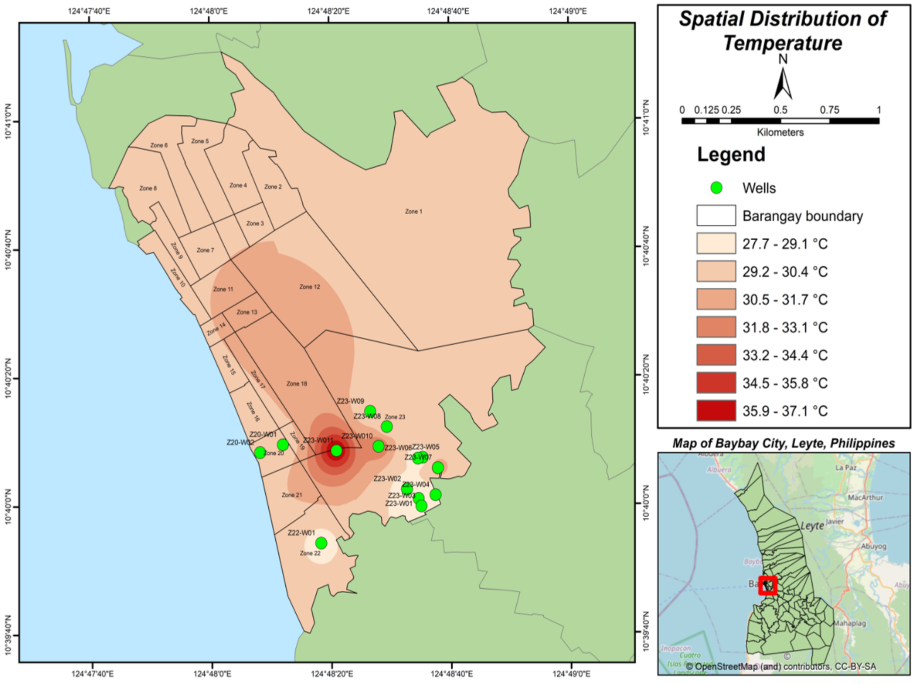

Figure 6. Spatial distribution of temperature (°C) in the study area

Nitrate. Nitrate analysis was conducted on a limited sample of seven wells, including two pump wells and three deep artesian wells that naturally flow under their own pressure without pumping. These three wells were selected due to their compliance with the laboratory's minimum depth criterion of 3m. In addition, two other shallow and open wells were purposely included in the analysis, with one located near a public cemetery and the other having a history of waterborne disease incidents, explicitly referring to Well 1 in Zone 23. This is significant since nitrate-contaminated water poses risks to humans when consumed or used in food preparation (WHO, 2022).

The average nitrate concentration in the sampled wells was 0.0205mg L^{-1}, ranging from 0.02mg L^{-1} to 0.39mg L^{-1}. Nitrate levels might be higher in the wells closer to a cemetery due to leachate from decaying human bodies. Research conducted in Tanzania by Leonard (2022) found a correlation between the location of wells near cemeteries and elevated nitrate levels. The study found that nitrate concentrations varied from 9.21mg L^{-1} to 239.5mg L^{-1}, with 91.3% of the tested wells exceeding the maximum allowable limit (MAL) 50mg L^{-1}. The decomposition of human bodies, producing leachate rich in nitrogen compounds, was identified as a possible cause of groundwater contamination. The leachate from a cemetery on Ontario was reported to contain 60% water and 30% salts, including nitrogen and phosphorus compounds, chloride, bicarbonate ions, metals, and organic substances (Beak Consultants Ltd., 1992).

Water containing nitrate concentrations exceeding 10mg L^{-1} of nitrate-N can lead to methemoglobinemia in individuals consuming it (WHO, 2016). However, all seven sampled wells had nitrate concentrations ranging from 0.02mg L^{-1} to 0.39mg L^{-1} (Figure 7). These values are within the safe limits set by the US EPA (2013) with a maximum contaminant level (MCL) of 10mg L^{-1} and the PNSDW (2017) with a maximum allowable limit (MAL) of 50mg L^{-1}, indicating that there is no indication of a nitrate issue in the drinking water supply.

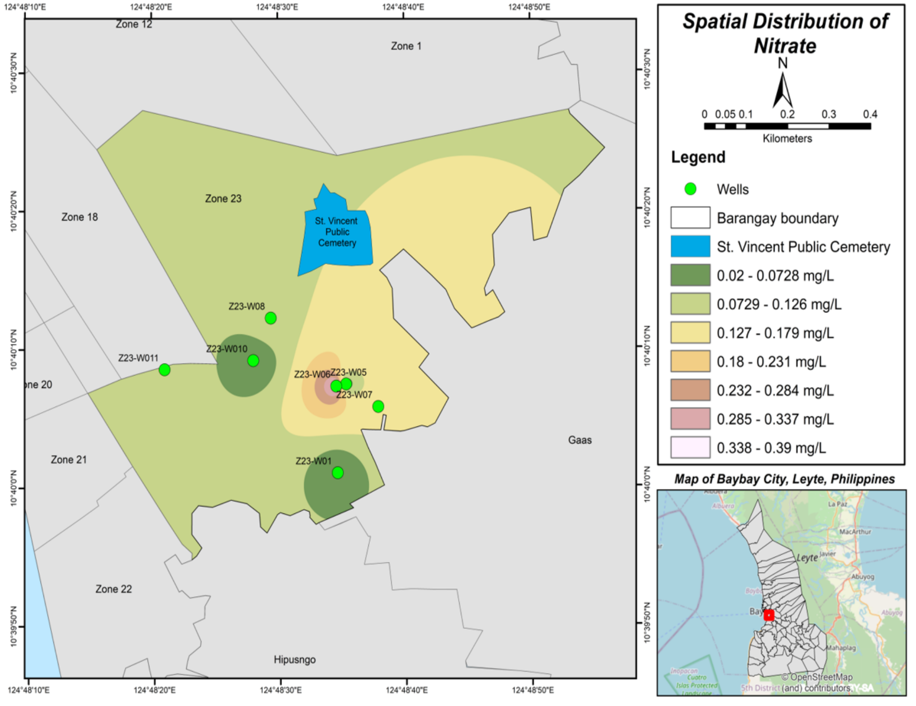

Figure 7. Spatial distribution of nitrate (mg L^{-1}) in the 7 wells

Dissolved Oxygen (DO). The mean dissolved oxygen (DO) concentration was 2.43mg L^{-1}, ranging from 1.28mg L^{-1} to 3.48mg L^{-1} (Figure 8). These values fall within the safe limit PNSDW (2017) established, which sets the MAL for DO at 6mg L^{-1}. Sitio Calvary, *Poblacion* Zone 23, Well 9, exhibited the highest DO concentration. However, the DO levels in wells with higher temperatures were lower than 2mg L^{-1}. The observed pattern is attributed to the influence of water temperature, which plays a crucial role in determining water's ability to retain dissolved oxygen. As temperature rises, dissolved oxygen levels typically decline, demonstrating an inverse relationship (Post et al., 2018; Sumaria, 2024).

The lowest DO concentration was recorded in Zone 23 *Poblacion* Well 11, which had a concentration of 1.28mg L^{-1}, coinciding with the highest recorded water temperature. According to the study in Indonesia by Brontowiyono et al. (2022), the dissolved oxygen (DO) levels exhibited their peak values during the rainy season, whereas the concentration was at its lowest during the dry season. Better water quality is associated with higher dissolved oxygen concentrations (Hassan Omer, 2020). As per WHO (1996), dissolved oxygen does not directly influence an individual's health.

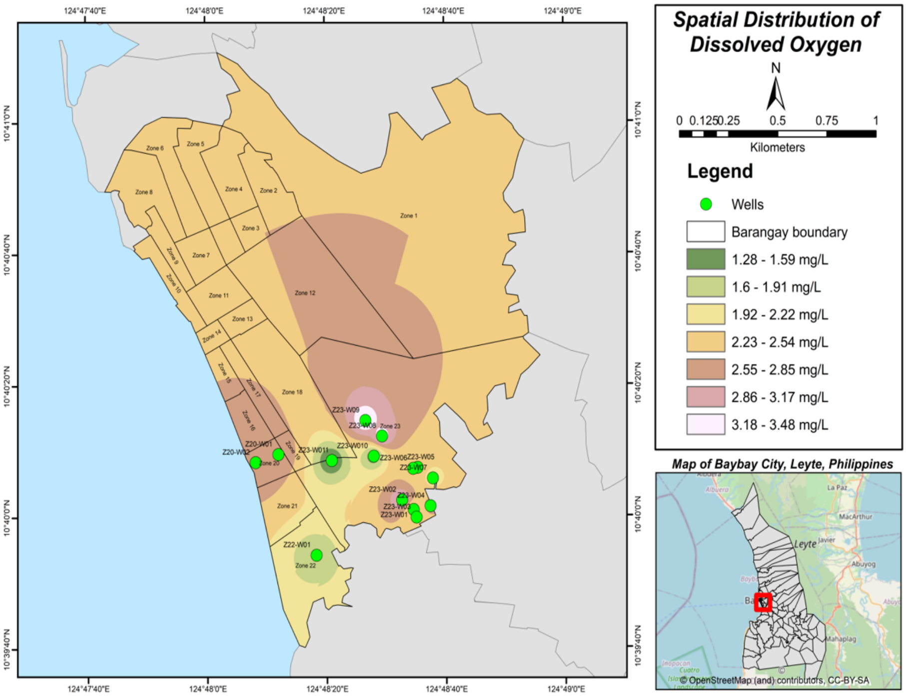

Figure 8. Spatial distribution of dissolved oxygen (mg L^{-1}) in the study area

Total Dissolved Solids (TDS). The mean Total Dissolved Solids (TDS) value was 824.19mg L^{-1}, ranging from 254.4mg L^{-1} to 1,328.2mg L^{-1} (Figure 9). The highest TDS concentration was in Sitio Yopa, *Poblacion* Zone 23, Well 7. As per Islam et al. (2017) and the findings by Jurgen (2004), water with a TDS concentration below 500mg L^{-1} is commonly regarded as having favorable taste qualities.

Among the samples analyzed, only one out of the 14 wells (7.14%) met the acceptable TDS value of approximately 600mg L^{-1} (PNSDW, 2017) and about 500mg L^{-1} (US EPA, 2015). This well is located in Sitio Looc, *Poblacion* Zone 23, and is identified as Well 4. Based on TDS values, 11 out of 14 wells (78.57%) have TDS concentrations lower than 1,000mg L^{-1}, classifying them as freshwater. On the contrary, three of the fourteen wells under consideration (21.43%) are artesian wells and exclusively used for cooking, while two are used for drinking purposes. These wells display TDS concentrations exceeding 1,000mg L^{-1}, consequently classifying them as brackish water sources (Carroll, 1962).

In accordance with evaluations conducted by tasting panels, the flavor profile of drinking water has been scrutinized relative to Total Dissolved Solids (TDS) concentrations. The evaluation scale rates water taste as excellent for levels below 300mg L^{-1}, good for concentrations between 300 and 600mg L^{-1}, fair for the range of 600 to 900mg L^{-1}, poor for TDS between 900 and 1,200mg L^{-1}, and unacceptable for levels exceeding 1,200mg L^{-1} (WHO, 1996). Following this evaluative framework, Well 7 in *Poblacion* Zone 23 exhibits an unacceptable taste, while Wells 6, 10, and 11 in the same zone demonstrate poor taste. Conversely, the remaining wells are characterized as having good taste, with Well 4 in this zone distinguished for its excellent taste.

According to the Safe Drinking Water Foundation, while a high concentration of total dissolved solids (TDS) is generally not an immediate health risk, it can signal the potential presence of other harmful substances. Additionally, increased TDS levels have the potential to induce gastrointestinal distress, even from minerals typically considered non-harmful (Hancock, 2016).

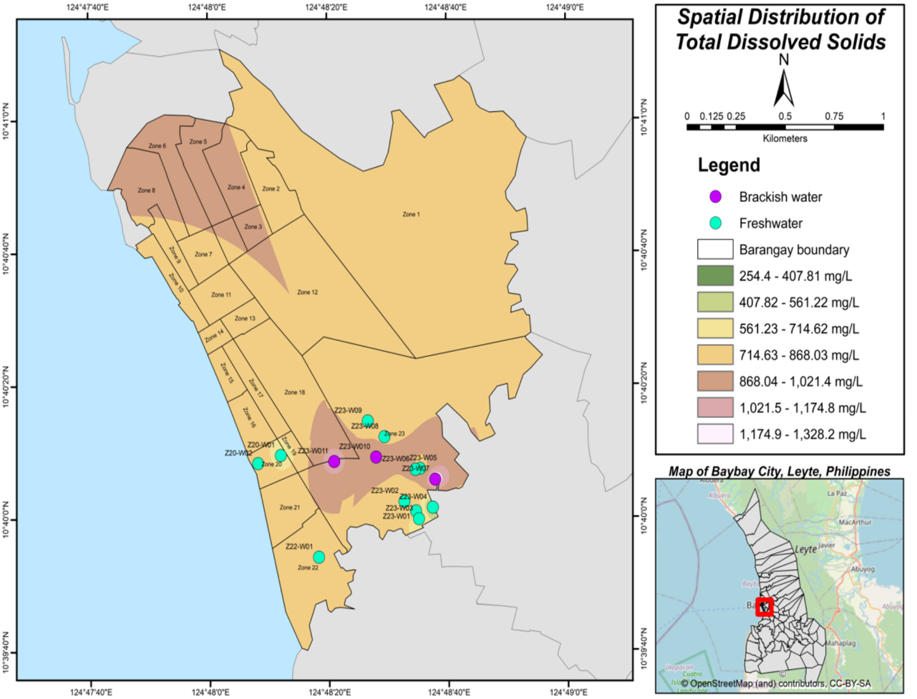

Figure 9. Spatial distribution of total dissolved solids (mg L^{-1}) in the study area

Electrical Conductivity (EC). In water, conductivity is influenced by the presence of inorganic dissolved solids, including chloride, nitrate, sulfate, and phosphate anions (negatively charged ions), as well as sodium, magnesium, calcium, iron, and aluminum cations (positively charged ions) (US EPA, 2012). Higher ion concentrations in water lead to increased conductivity. Additionally, temperature plays a significant role, as warmer water generally exhibits higher conductivity levels (US EPA, 2018b).

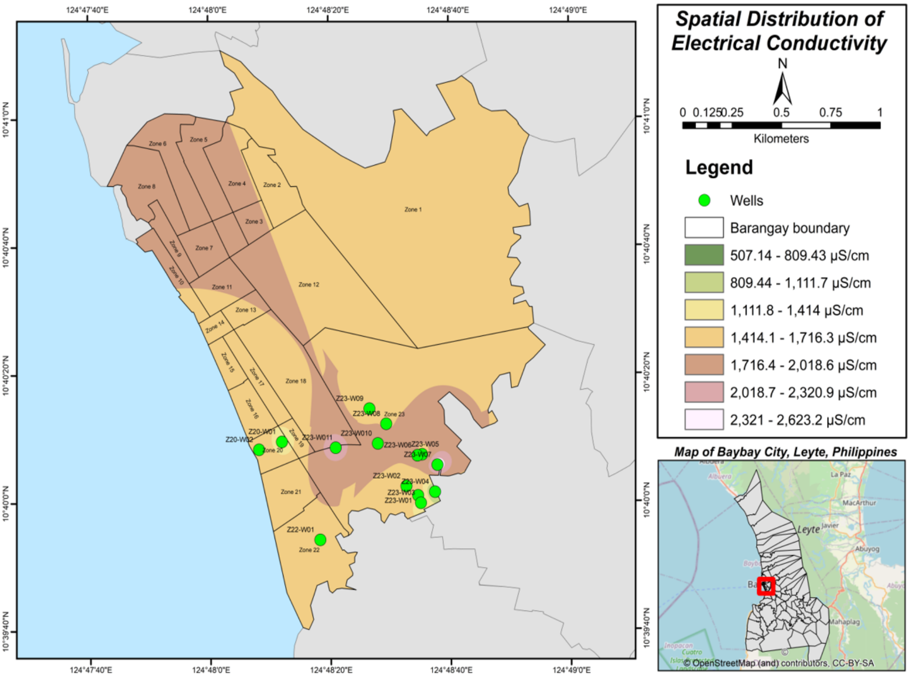

Figure 10. Spatial distribution of electrical conductivity (uS cm^{-1}) in the study area

In this study, the mean Electrical Conductivity (EC) value was determined to be 1,646.67uS cm^{-1}, ranging from 507.14uS cm^{-1} to 2,623.2uS cm^{-1} (Figure 10). The highest EC value of 2,623.33uS cm^{-1} was observed in Sitio Yopa, *Poblacion* Zone 23, Well 7. Well 10 in Sitio Calvary and Well 11 in E. Jacinto St. also exhibited EC values exceeding 2,000uS cm^{-1}.

Out of the 14 wells studied, nine wells (64.29%) surpassed the maximum allowable limit for conductivity, set at 1,500uS cm^{-1} (PNSDW, 2017). This indicates that there is a high level of contamination from dissolved ions. Contaminants like sodium, potassium, or chloride might exist in these wells (Orebiyi et al., 2010).

Rajankar et al. (2011) employ a conductivity-based classification system for water quality: excellent (<250µS cm^{-1}), good (250-750µS cm^{-1}), permissible (750-2,000µS cm^{-1}), doubtful (2,000-3,000µS cm^{-1}), and unsuitable (>3,000µS cm^{-1}). By these figures, Well 4 in *Poblacion* Zone 23 is the sole representative of good water quality, while ten additional wells conform to the criteria for permissible water quality. Conversely, Wells 7, 10, and 11 in the same zone evoke concern due to their classification as having doubtful water quality.

Dieu et al. (2022) employed cross-section lines to visualize TDS distribution, analyzing water samples from diverse depths and locations. This method provided insights into water quality and identified areas for further investigation or treatment. In this study, two cross-section lines, spanning from Zone 20 to Zone 23 and Zone 22 to Zone 23, were drawn from lower to higher elevations. The elevation profile in Figure 11 shows decreasing EC and TDS curves as the distance of the well to the shoreline increases and the well's elevation rises.

Assessment of the water quality in selected groundwater wells

Figure 11. Elevation Profile vs. Electrical Conductivity (EC) vs. Total Dissolved Solids (TDS) from the study site cross-section

Salinity. The presence and concentration of dissolved salts in water significantly impact its quality. According to the World Health Organization (WHO), salinity levels in groundwater can be categorized based on grading criteria. High-grade drinking water is characterized by salinity below 600mg L^{-1}, while salinity ranging from 600 to 900mg L^{-1} is considered fair quality. Salinity exceeding 1,200mg L^{-1} is deemed undesirable.

In the studied area, salinity levels ranged from 0.18 parts per thousand (ppt) to 1.35ppt (equivalent to 180mg L^{-1} to1,350mg L^{-1}). Among the wells analyzed (Figure 12), only Well 4 in Sitio Looc, Poblacion Zone 23, exhibited high-grade drinking water quality, with a 180mg L^{-1} salinity level. Approximately 64.29% of the wells (9 out of 14) fell within the fair quality range. Notably, Sitio Yopa, Poblacion Zone 23 Well 7, displayed the highest salinity, measuring 1,350mg L^{-1}, which is considered undesirable for drinking. Ingesting water with elevated salinity can pose various health risks. Excessive salts may overload the kidneys, impairing their function and potentially leading to kidney failure, heart problems, high blood pressure, and stroke. Additionally, the consumption of saline water may induce symptoms like diarrhea and abdominal pain, causing dehydration, electrolyte imbalances, and gastrointestinal distress (Chakraborty et al., 2019).

Coliform Test. Seven water samples from wells in Zones 20 and 23 of Baybay City, Leyte, were tested for fecal coliforms, as illustrated in Figure 13. Five of the seven samples showed fecal contamination. Approximately 71.43% of the wells are unsafe for drinking due to Escherichia coli (E. coli) contamination.

The total coliform (TC) and fecal coliform (FC) levels in wells Z20-W01, Z20-W02, Z23-W01, Z23-W05, and Z23-W07 exceed the safe limit of less than 1.1MPN/100mL. These wells are located near clusters of two to 20 septic tanks within the 25m buffer.

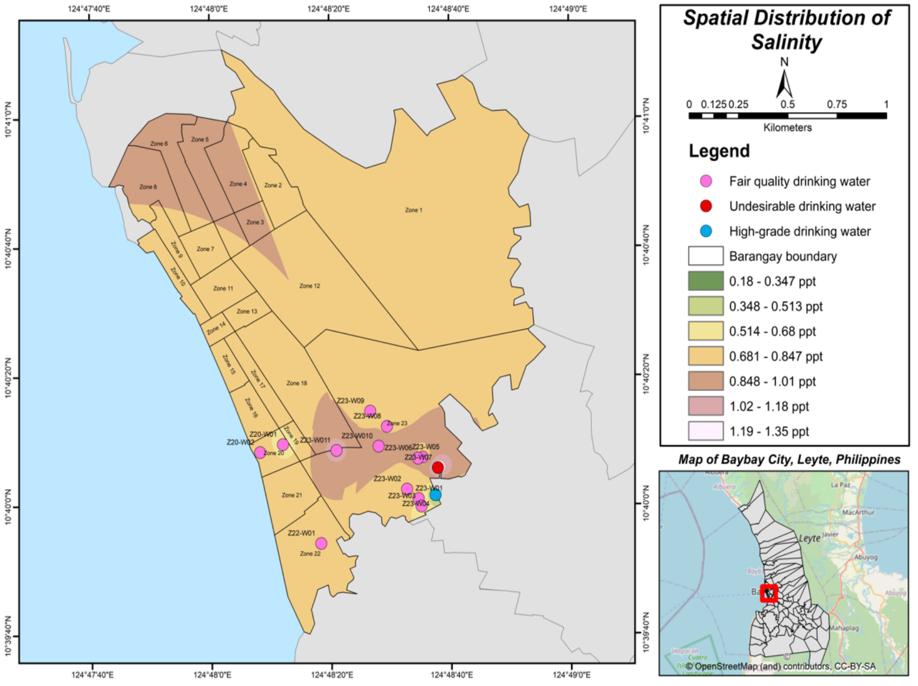

Figure 12. Spatial distribution of salinity (ppt) in the study area

The substantial discharge of untreated wastewater near these wells causes fecal contamination, introducing harmful bacteria, viruses, and parasites into the water. This contamination poses serious health risks when the water is used for drinking, cooking, or bathing, potentially leading to diseases such as gastroenteritis, cholera, and hepatitis (Perkins, 1984; Yates, 1985). The presence of fecal coliforms indicates recent contamination and raises concerns about dangerous pathogens in the water (Pal, 2014). However, wells Z23-W010 and Z23-W011 passed the test, with coliform levels below the safe limit.

Water Quality Status of Groundwater Wells in the Study Area

The physicochemical and microbiological quality of groundwater from 14 wells in *Poblacion* Zones 20, 22, and 23 is summarized in Table 1. Results indicate that none of the wells met the minimum standards for potable water, with the majority exceeding recommended limits in several key parameters. Commonly exceeded parameters included temperature, salinity, electrical conductivity (EC), and total dissolved solids (TDS). Microbiological contamination, particularly total and fecal coliforms, was also observed in wells where water was used for domestic purposes.

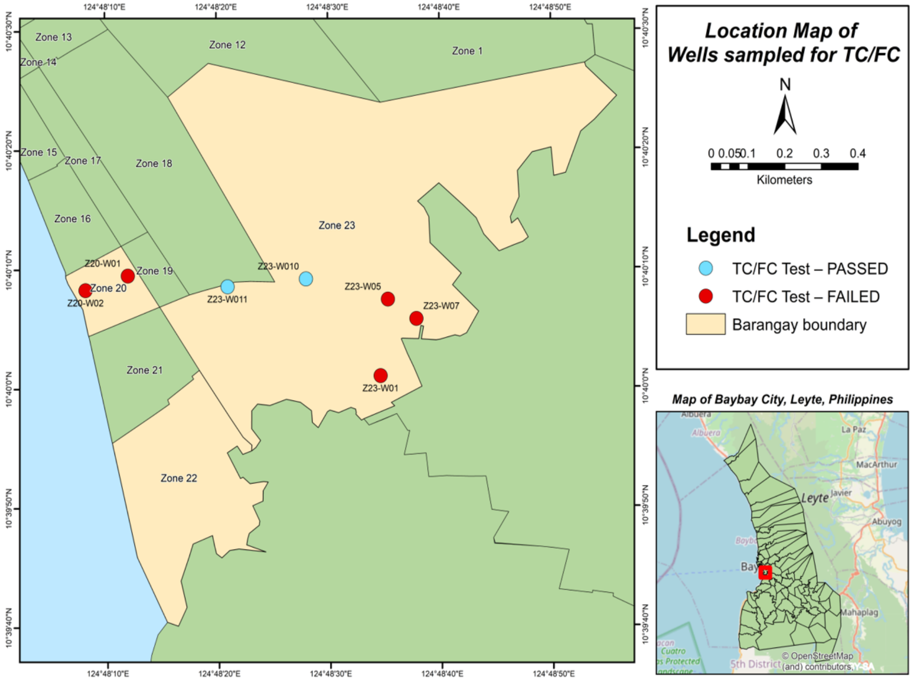

Figure 13. Location of wells sampled for total coliforms and thermotolerant (fecal) coliforms in the study area

In this study, nitrate was only measured in a limited number of wells, primarily those used for drinking and cooking. Wells used solely for non-potable purposes (e.g., cleaning, laundry, irrigation) were excluded from nitrate testing due to limited testing resources and adherence to a risk-based approach to water quality monitoring. According to WHO (2017) and the Philippine Department of Health (DOH, 1993), nitrate testing is prioritized for wells used for ingestion to better assess public health risks. Although only Well Z23-W05 yielded nitrate data (0.02mg L^{-1}), which is below the WHO guideline of 10mg L^{-1} NO – N, the absence of nitrate testing in other wells does not eliminate the potential for contamination, particularly those located near residential septic systems or agricultural runoff.

All wells exceeded at least two safety parameters. Temperature exceeded recommended levels in 100% of tested wells, potentially due to shallow well depth or insufficient natural insulation, which may accelerate microbial growth and affect solubility of other contaminants (WHO, 2017). More than 90% of the wells exhibited elevated salinity and EC, indicative of high ionic content or saltwater intrusion, a common issue in coastal groundwater systems (Abbas et al., 2023; Morgan et al., 2013). Similarly, high TDS levels were observed in most wells, which can impair taste and contribute to chronic health effects such as kidney stress and gastrointestinal irritation (US EPA, 2018a). Fecal coliforms were detected in several wells, including those used for drinking (e.g., Z23-W07, Z23-W011), suggesting potential exposure to enteric pathogens and a heightened risk of waterborne diseases (Howard et al., 2003).

Table 1. Summary of water quality parameters and usage profiles of sampled wells

Well Designation	Zone	Uses	Nitrate	pH	Temperature	DO	TDS	EC	Salinity	TC/FC	Remarks
Z20-W01	Zone 20	Bathing, Laundry, Cooking, Cleaning, Irrigation	Not tested	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Not Safe
Z20-W02	Zone 20	Cooking, Bathing, Laundry, Cleaning, Irrigation	Not tested	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Exceed Limit	Exceed Limit	Not Safe
Z23-W01	Zone 23	Laundry, Bathing, Cooking, Cleaning, Irrigation	Within Limit	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Exceed Limit	Exceed Limit	Not Safe
Z23-W02	Zone 23	Laundry, Irrigation, Cleaning, Bathing	Not tested	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Exceed Limit	Not tested	Not Safe

Note: pH – potential hydrogen; DO – dissolved oxygen; TDS – total dissolved solids; EC – electrical conductivity; TC/FC – total coliform/fecal coliform. "Within Limit" and "Exceed Limit" refer to compliance with Philippine National Standards for Drinking Water.

Table 1. continued

Well Designation	Zone	Uses	Nitrate	pH	Temperature	DO	TDS	EC	Salinity	TC/FC	Remarks
Z23-W04	Zone 23	Laundry, Cleaning, Bathing, Irrigation	Not tested	Within Limit	Exceed Limit	Within Limit	Within Limit	Within Limit	Within Limit	Not tested	Not Safe
Z23-W05	Zone 23	Laundry, Irrigation, Cleaning, Bathing, Cooking	Within Limit	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Not Safe
Z23-W06	Zone 23	Cleaning, Laundry, Bathing, Irrigation	Within Limit	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Exceed Limit	Not tested	Not Safe
Z23-W07	Zone 23	Drinking, Cooking, Bathing, Laundry, Cleaning, Irrigation	Within Limit	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Exceed Limit	Exceed Limit	Not Safe
Z23-W08	Zone 23	Cleaning, Irrigation, Laundry, Bathing	Within Limit	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Exceed Limit	Not tested	Not Safe

Table 1. continued

Well Designation	Zone	Uses	Nitrate	pH	Temperature	DO	TDS	EC	Salinity	TC/FC	Remarks
Z23-W09	Zone 23	Laundry, Bathing, Cleaning, Irrigation	Not tested	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Exceed Limit	Not tested	Not Safe
Z23-W010	Zone 23	Irrigation, Cleaning, Laundry, Bathing, Cooking	Within Limit	Exceed Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Exceed Limit	Within Limit	Not Safe
Z23-W011	Zone 23	Laundry, Cleaning, Irrigation, Drinking, Cooking, Bathing	Within Limit	Exceed Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Exceed Limit	Within Limit	Not Safe
Z22-W01	Zone 22	Cleaning, Laundry, Irrigation, Bathing	Not tested	Within Limit	Exceed Limit	Within Limit	Exceed Limit	Exceed Limit	Exceed Limit	Not tested	Not Safe

The compromised quality of groundwater can be attributed to several environmental and anthropogenic factors. Many wells were situated within 25 meters of residential septic systems, in violation of the required setback distance under Presidential Decree No. 856 (DOH, 1995). Poorly designed or aging septic tanks may leak into shallow aquifers, especially in areas with permeable soils and high-water tables. In addition, the presence of drainage canals near the wells may allow the infiltration of urban and agricultural runoff containing nutrients, heavy metals, pathogens, and synthetic chemicals (Böhlke, 2002). Furthermore, several wells located in coastal areas, exhibited elevated EC and salinity levels, which are consistent with saltwater intrusion resulting from excessive groundwater extraction and aquifer drawdown (Abbas et al., 2023; Morgan et al., 2013).

Spatial Autocorrelation: Moran's I Statistics

The study utilized Moran's I (Table 2) statistic to examine spatial autocorrelation and determine if the measured factor exhibited a random distribution across the study site. In seven sampled wells, the results indicated significant spatial autocorrelation for nitrate level and well-to-shoreline distance. This suggests that nitrate levels and well distances displayed clustering patterns. The clustering of nitrate levels was attributed to the coexistence of low and high levels in neighboring sampling sites. Clustering nitrate levels in groundwater wells can have significant implications for water quality management. The coexistence of low and high nitrate levels in neighboring sampling sites suggests that the contamination source is localized and can be traced back to a specific area (Nemčić-Jurec et al., 2022).

Furthermore, while current levels pose no immediate health risk, the spatial pattern highlights areas that may be more vulnerable to contamination in the future. Therefore, continued localized monitoring and management are essential to detect and address potential risks before nitrate concentrations reach unsafe levels. The existence of nitrate in drinking water can result in numerous health issues, including methemoglobinemia, commonly known as Blue Baby Syndrome, which poses a heightened risk for infants below six months of age. Nitrate can also cause gastrointestinal illnesses, skin rashes, and neurological disorders (*"Nitrate"*, 2020).

Table 2. Moran's I statistics summary

Factor	Moran's I	*p*-value
Nitrate	-0.3809*	0.0399
pH	-0.1804	0.9299
pH Temperature	0.0010	0.2056
DO	-0.2334	0.6354
DO Temperature	-0.0263	0.3097
TDS	-0.2442	0.5743
EC	-0.2460	0.5702
Salinity	-0.2438	0.5752
Septic tank density	0.1116	0.0771
Well to shoreline distance	0.1120*	0.0355
2D IDW	-0.0815	0.5753

***Note**: *p* < 0.05 indicates statistical significance at the 5% level. pH - potential hydrogen; DO - dissolved oxygen; TDS - total dissolved solids; EC - electrical conductivity; 2D IDW – two-dimensional inverse distance weighting.

CONCLUSION

The study on groundwater quality in the Central (*Poblacion*) District, Baybay City shows the significant impact of septic systems on contamination. The assessment of 943 households across Zones 20, 22, and 23 reveals the extent to which failing or improperly placed septic tanks can pose risks to water sources. Findings reveal significant non-compliance with national sanitation standards, with many septic tanks situated well within the 25m buffer zone from drinking water sources. This proximity poses considerable risks of contamination, particularly nitrate leaching, which, while currently within safe limits, demonstrates spatial clustering that may escalate if not managed. Other water quality parameters including pH, temperature, dissolved oxygen, TDS, EC, and salinity also exhibited concerning trends in several wells, with some exceeding national or international drinking water standards. Elevated temperatures and conductivity suggest increased microbial activity and ion contamination, while high TDS and salinity levels may impair taste and raise long-term health concerns. The application of Moran's I spatial analysis confirmed the non-random distribution of nitrate levels, signaling localized contamination sources. Altogether, the results emphasize the need for stricter enforcement of septic tank regulations, regular desludging, and strategic groundwater monitoring to protect public health and ensure the long-term sustainability of drinking water sources in urbanizing coastal communities.

Given these findings, it is evident that certain septic tanks in the study area are not adhering to the prescribed minimum distances from water supply sources, posing potential risks to water quality and public health. In light of this, it is strongly recommended to enforce compliance with the construction standards outlined in Presidential Decree 856, particularly the requirement of maintaining a minimum safe distance of 25m between septic tanks and any groundwater wells or other sources of drinking water.

Acknowledgment

The authors express their deepest gratitude to Visayas State University for funding the analytical component of the study through the VSU Internationalization Program Project Code VSU-IP-2022-7. The authors also acknowledge the support provided by the Geographic Information System Services Unit (GISSU).

Author Contributions

BDG: Writing – original draft preparation, Conceptualization, Data curation, Visualization, Writing – review and editing. MGCS: Conceptualization, Writing – review and editing, Supervision, Funding acquisition.

Funding Source

This research was supported by the Visayas State University Internationalization Project, which provided funding for the analytical component of the study.

Availability of Data and Materials

Data will be made available on request.

Ethical Considerations

Not Applicable.

Competing Interest

The authors declare that they have no competing interests.

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