



Spatial mapping of groundwater quality in the municipality of Santa Ignacia, Tarlac, Philippines

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Abstract

The municipality of Santa Ignacia in the Province of Tarlac is highly dependent on groundwater as its major water supply for various purposes, but there is inconsistency in monitoring groundwater quality in the area which may impact the health of consumers. This study presented the preliminary assessment of groundwater quality through the application of spatial mapping. Out of 6,815 wells in the municipality, groundwater samples were collected from 274 hand pump wells. The measurements of selected groundwater quality parameters such as pH, conductivity, nitrate, nitrite, and iron of groundwater samples were determined on-site. The geographical coordinates of sampled wells and measurements of groundwater quality parameters were used in Geographic Information System software, QGIS, to construct the spatial distribution and spatial variation maps. The values of measured parameters were interpolated using the inverse distance weighted technique to predict the parameters at other sites in Santa Ignacia. Spatial variation maps revealed that the groundwater quality parameters varied in the municipality. All measured parameters, except the nitrite content, were within the acceptable limits set by the World Health Organization for drinking water. The high level of nitrite content in groundwater may be attributed to the application of fertilizers during agricultural activities. The nitrite content of groundwater, which exceeded the permissible limit, may cause long-term public health problems. Hence, an upscale evaluation and monitoring of groundwater quality and existing anthropological activities in the municipality are highly recommended. The identification of other possible source(s) of nitrite is necessary to lessen possible contamination risk and to protect the groundwater sources in the municipality. The results of this preliminary study would be useful in prospect studies of groundwater quality in the study area and in other provinces in the Philippines.

Keywords Groundwater · Groundwater quality · Drinking water · Spatial mapping · Geographic information system

Introduction

Groundwater refers to water found beneath the ground surface in cracks and spaces in soils, sands, and rocks. It comprises about 20% of freshwater resources worldwide and used for domestic and irrigation purposes in urban and rural populations. In terms of frequency and volume, it is the most extracted raw material worldwide and the Philippines has an extensive groundwater reservoir with an aggregate area of approximately 50,000 square kilometers. In the Philippines, groundwater is the preferred water source in rural water supply systems, particularly wells. Wells are holes constructed

to withdraw water from underground aquifers and are considered level 1 water supply. Level 1 water supply provides a protected well with an outlet but lacking in the distribution system; hence, it is adaptable for rural areas where it is accessible, and houses are not crowded (Greenpeace 2007; Usha et al. 2011; World Bank 2012; Margat and van der Gun 2013; Shakerkhatibi et al. 2019).

Degradation of water quality is one of the problems of the twenty-first century. Water contamination degrades the quality of water making it unsafe to use, leading to detrimental health effects. Water quality is determined by its physical properties, chemical composition, and biological parameters. The levels of parameters indicate whether the water is safe for consumption. Otherwise, the water is needed to be treated to acceptable standards by reducing them to levels determined by regulatory authorities. Furthermore, when raw water quality is fully understood, the most

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appropriate water purification method can be determined. Groundwater is generally accepted as a safe water source for human consumption; however, it is not ubiquitously free from contaminants. Regular monitoring of groundwater is necessary to ensure that water is safe and usable, and the quality of water is acceptable (Oki and Akana 2016; Murphy et al. 2017; Patella et al. 2017; AlSuhaimi et al. 2019; Dev and Bali 2019).

A groundwater quality map is an important tool for managing groundwater to ensure optimal and sustainable use and to protect public health. Inverse distance weighting (IDW) is a Geographic Information System (GIS) interpolation technique that is widely used to produce groundwater quality map. It is a technique performed to interpolate measured data to show spatial variations, and it follows a deterministic model approach in which unknown values are computed based on nearby points. It is not always feasible to sample groundwater at every location due to high costs and time involved in sampling; hence, this technique provides a solution to optimally predict groundwater quality at other locations based on measured parameters. Understanding differences in groundwater quality is necessary to effectively monitor groundwater (e.g., the extent of groundwater contamination). Generating such information is useful in facilitating groundwater management and in decreasing contamination risk of groundwater sources (Ketata-Rokhani et al. 2011; Adnan and Iqbal 2014; Korbel et al. 2016; Kawo and Karuppannan 2018; Chaudhry et al. 2019; Masocha et al. 2019).

To date, studies on groundwater quality assessment using Geographic Information System are lacking in the Philippines. The present study measured selected groundwater quality parameters and produced spatial variation maps to determine possible drinking water contamination.

Materials and methods

Study area

The municipality of Santa Ignacia is a second-class municipality in Central Luzon and is situated on the western side of Tarlac Province (15.5841°N and 120.4588°E; Fig. 1). It has a total land area of 14,607 hectares consisting of 24 barangays in which two are in the urban area while the rest are in rural areas. The topography of the municipality is roughly rolling to hilly and mountainous. It has two well-defined seasons, the wet (June to October) and dry seasons (November to May). Based on the data obtained from the Field Health Service Information System in 2017–2018, from the Municipal Health Office, the municipality has a total number of 6,815 deep wells and shallow wells as groundwater sources.

Groundwater sampling

A total number of 274 groundwater samples were collected from hand pump wells, used for drinking and/or bathing, from January to March 2019 (Fig. 2). Geographical coordinates (latitudes and longitudes) of the wells were recorded using a calibrated hand-held Global Positioning System (GPS) (eTrex®—Garmin). Water samples were collected using 1 L sterile, properly labeled, polyethylene bottles. Before the collection of water samples, sampling bottles were washed with distilled water, and the sample water itself 2–3 times, and wells were pumped for 5 to 10 min before the sampling. Collected water samples were kept in an icebox and transported to De La Salle University, Science and Technology Research Center laboratory for processing.

Groundwater quality parameters

Five groundwater quality parameters were measured in situ which include pH, conductivity, nitrate, nitrite, and iron. The selected parameters were based on the Philippine Department of Environment and Natural Resources (DENR) groundwater quality guidelines. The pH and conductivity ($\mu\text{mho/cm}$) of the groundwater samples were measured using pH meter (ExStik®) and conductivity meter (Yellow Spring Instrument Co., Inc., Yellow Springs, Ohio, USA), respectively. The levels of nitrate, nitrite, and iron were determined using water quality test strips and testing kits (OMEGA Engineering, Singapore).

Statistical analysis and mapping of groundwater quality parameters

Descriptive statistics were used to analyze the measurements of groundwater quality parameters. Using the Geographic Information System software, QGIS version 2.18.24, a map showing the distribution of sampled wells from the study area and spatial variation maps of measured groundwater quality parameters were constructed using the recorded geographical coordinates and inverse distance weighted interpolation method, respectively.

Results and discussion

The characterization of groundwater in Santa Ignacia based on pH, conductivity, nitrate, nitrite, and iron is summarized in Table 1 and Fig. 3. The pH of groundwater samples ranged from 6.00 to 8.00 with an average of 6.56. The conductivity of water samples ranged from 0.00 to 500.00 ($\mu\text{mho/cm}$) with an average of 97.16 ($\mu\text{mho/cm}$).

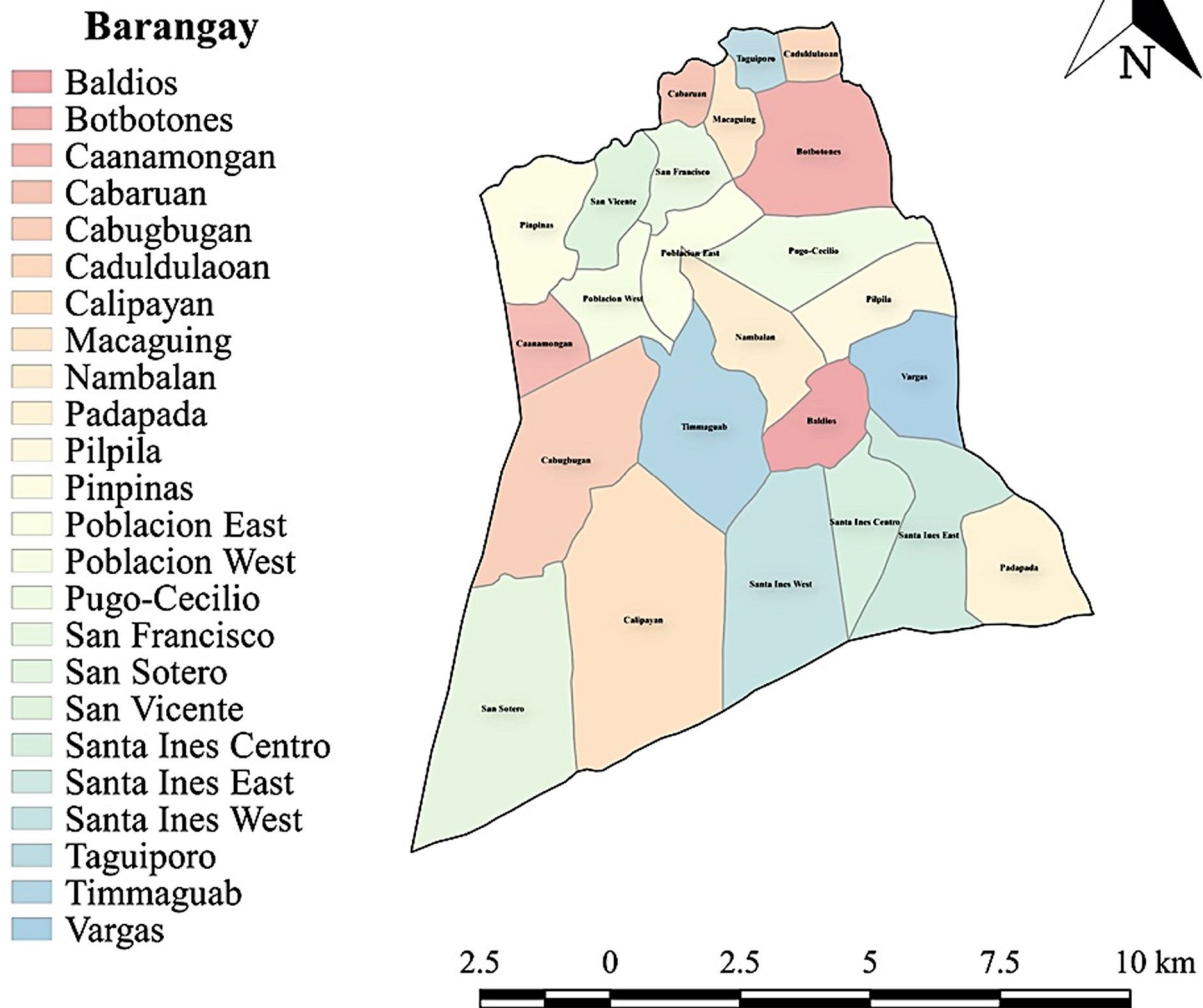


Fig. 1 Constructed map, using Geographic Information System software, QGIS, showing the entire land area of the study area, Santa Ignacia, Tarlac, Philippines

For both nitrate and nitrite, minimum and maximum values were 0.00 and 20.00 mg/L while average nitrate and nitrite were 0.81 mg/L and 0.51 mg/L, respectively. The iron content of the samples ranged from 0.00 to 2.00 mg/L with an average of 0.03. Generally, the mean values of all groundwater parameters were within the permissible limits set by the DENR and WHO.

Santa Ignacia has a total number of 6815 wells; however, in this study, only 274 groundwater samples were obtained due to time and resource limitations. Thus, the inverse distance weighting technique was used to interpolate measured data from various sites and predict the groundwater quality at other sites in Santa Ignacia. Using inverse distance weighting, spatial maps for each groundwater quality parameter were constructed to visualize the overall quality of groundwater in Santa Ignacia. As shown in the spatial maps,

the groundwater quality in the municipality of Santa Ignacia varied greatly across sites (Fig. 4).

Slightly acidic pH values (≤ 6.29) of groundwater were observed in groundwater in Botbotones, Caanamongan, Cabaruan, Cabugbugan, Macaguig, Nambalan, Pinpinas, Poblacion East, Poblacion West, San Francisco, San Vicente, Taguiporo, and Vargas, which were below the permissible limit for pH (6.5 to 8.5) set by the World Health Organization (2008). Slightly acidic and neutral pH values (> 6.58) were recorded in Botbotones, Cabugbugan, Caduldulaoan, Calipayan, Nambalan, Padapada, Pilpila, Pugo Cecilio, San Sotero, Santa Centro, Santa Ines East, Santa Ines West, Taguiporo, and Vargas, which were within the permissible limit. The value of pH is influenced by the amount of hydrogen present in groundwater. It measures from 0 to 14 where 7 is neutral. Also, the formation of carbonic acid, through

Fig. 2 Spatial distribution of sampled wells in Santa Ignacia, Tarlac, Philippines

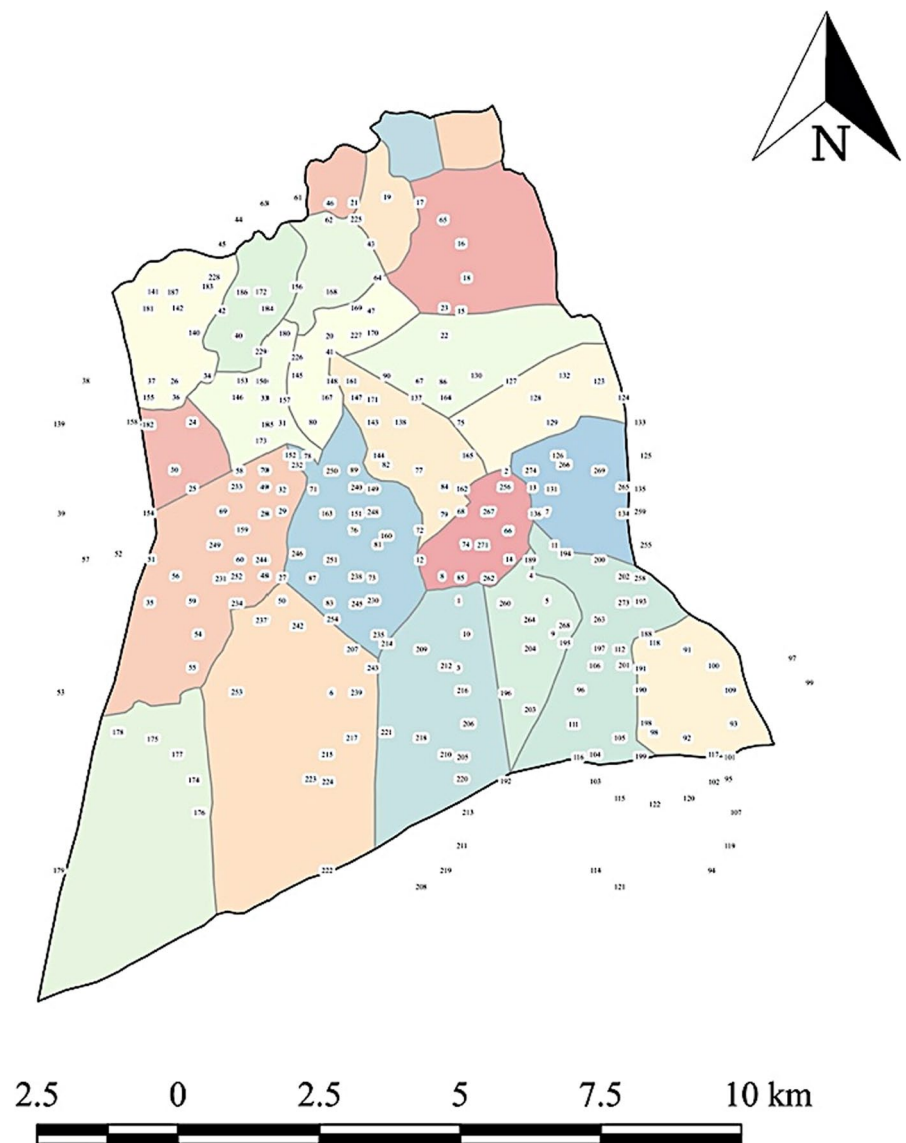


Table 1 Descriptive statistical analyses of measured selected groundwater quality parameters

	pH	Conductivity (µmho/cm)	Nitrate (mg/L)	Nitrite (mg/L)	Iron (mg /L)
Minimum	6.00	0.00	0.00	0.00	0.00
Maximum	8.00	500	20.00	20.00	2.00
Mean	6.56	97.16	0.81	0.51	0.03
SD	0.55	156.50	2.34	2.48	0.14
Median	6.65	40.00	0.00	0.00	0.00
DENR*	6.5–8.5	–	7	–	1
WHO*	6.5–8.5	1,000	50	3	0.3

*- Permissible limits set by the Department of Environment and Natural Resources (DENR 2016) & the World Health Organization (World Health Organization 2008)

The bold texts represent the permissible limits set by the Department of Environment and Natural Resources & the World Health Organization

the combination of carbon dioxide and water, affects the pH of groundwater (Khan et al. 2005; Nagaraju et al. 2006;

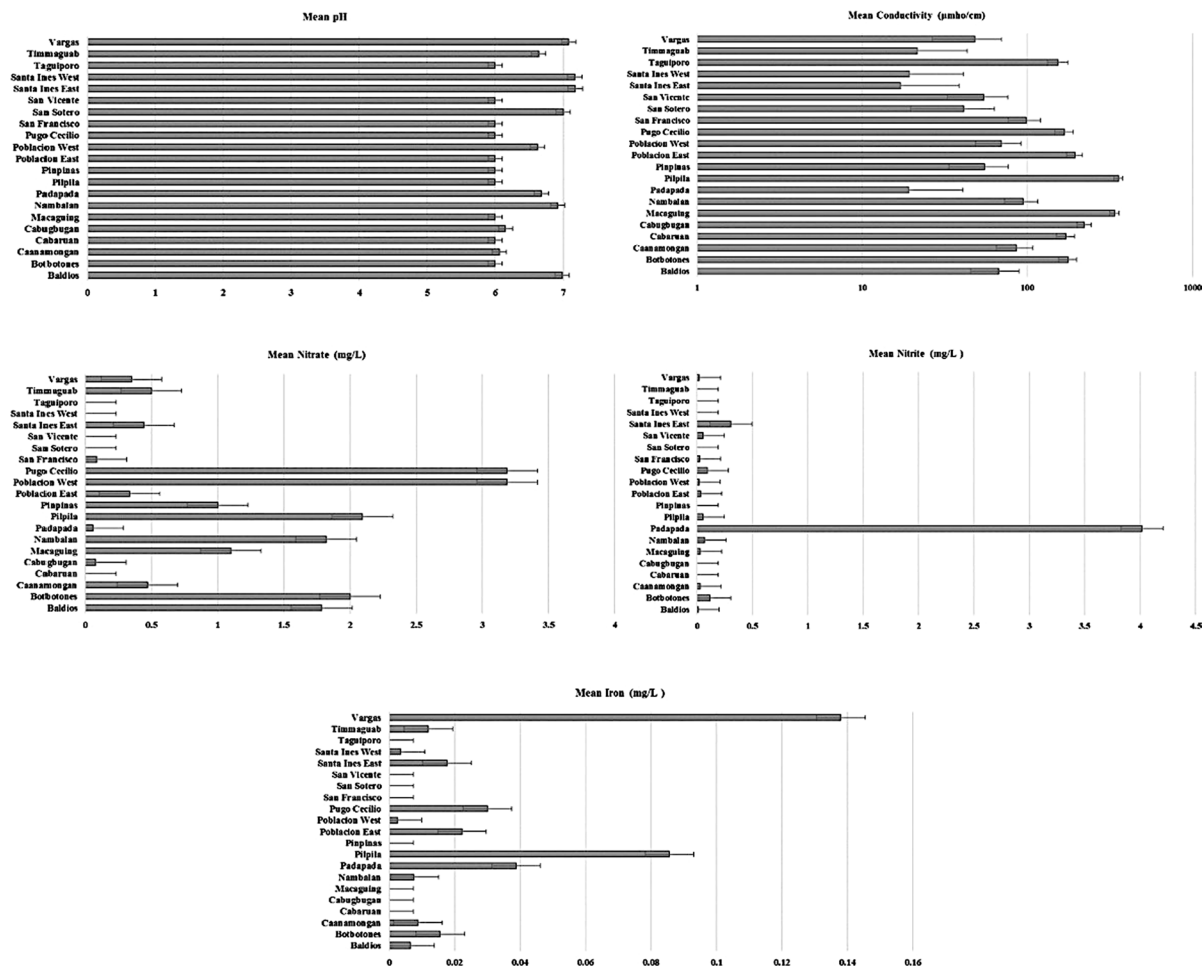


Fig. 3 The mean values of measured groundwater quality parameters across study sites. The error bars represent standard error

Krishna et al. 2015; Hejaz et al. 2020).

High conductivity (> 199 µmho/cm) was observed in groundwater in Cabugbugan, Nambalan, Pilpila, San Francisco, and Vargas, but within the permissible limit (1000 µmho/cm). The efficiency of groundwater to conduct electricity is expressed by electrical conductivity. The availability of electrolytes in the groundwater system is the consequence of the dissolution of minerals by water. Water from precipitation infiltrates the soil, dissolves minerals, and carries suspended particles along its path (Prakash and Somashekar 2006; Chegbeleh et al. 2020).

High nitrate concentration (> 3.53 mg/L) in groundwater was observed in Pilpila and Vargas but within the acceptable limit (50 mg/L). The highest nitrite content in groundwater was in Padapada (> 14.5 mg/L) which has exceeded the permissible limit (3 mg/L). The highest iron concentration (> 0.0938 mg/L) in groundwater sources was in Nambalan and Vargas but also within the acceptable limit (0.3 mg/L). Nitrate, nitrite, and iron are trace metals that are usually present in groundwater sources.

Trace metals significantly affect groundwater quality and affect human health if the level is higher than the acceptable limit (Bibi et al. 2007; Oseke et al. 2021). Nitrate and nitrite are the forms of nitrogen compounds usually present in groundwater. Nitrite is known to be more toxic to human health than nitrate. Nitrite is hazardous, particularly to infants and pregnant women (Varol and Davraz 2015; Baba et al. 2020).

All measured groundwater quality parameters, except the nitrite content, were found to be within the permissible limits set by the World Health Organization for drinking water. The means of livelihood among the populace of Santa Ignacia is agriculture. The majority of the total land area of the municipality is devoted to the cultivation of agricultural products. Fertilizers applied to the soil during agricultural activities may contain organic nitrogen that is broken down to nitrite and nitrate. Nitrate and nitrites can readily move with groundwater during leaching and may accumulate in the aquifer. Consequently, the high concentration of nitrite in groundwater can be attributed to the high agricultural

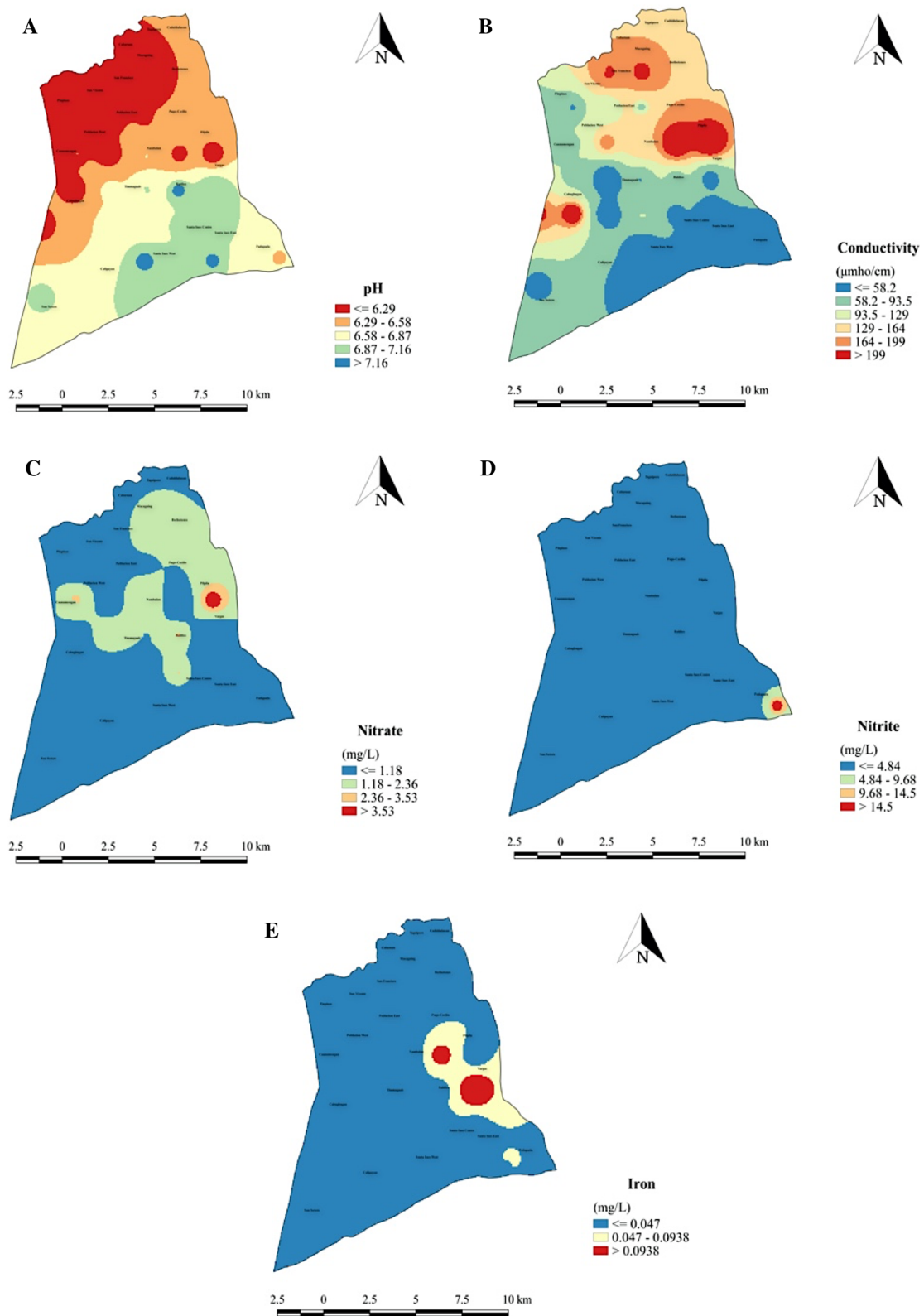


Fig. 4 Spatial variation maps of measured groundwater quality parameters in Santa Ignacia, Tarlac. A- pH, B- conductivity ($\mu\text{mho/cm}$), C-nitrate (mg/L), D- nitrite (mg/L), E- iron (mg/L)

and/or other anthropological activities in the area. It is also important to take note that other factors may affect the concentration of nitrite in groundwater, such as the oxidation of waste products from human and animal feces (World Health Organization 2004; Daghara et al. 2019; World Water Quality Alliance 2021).

The general results revealed that there is a significant variation in the measured groundwater quality parameters among the sampling sites in the study area. The identification of the cause of groundwater contamination and pollution is challenging because the problem remains concealed well below the surface. Diversity in topography causes variation in the physical and chemical composition of groundwater. Inputs from natural resources such as atmosphere, soil and water–rock weathering, and anthropogenic factors including mining, agriculture, and domestic and industrial wastes are reflected in groundwater quality parameters. The quality of groundwater also depends on the aquifer's size and the geological formation of underlying strata. Hence, constant changes in daily, seasonal, and climatic factors, local and regional geology, water/rock interactions instinctively affect groundwater quality (Hussain et al. 2010; Ackah et al. 2011; Zaidi et al. 2015; Yuan et al. 2017).

In the Philippines, the minimum frequency of sampling for level 1 water supply, such as wells, for physical and chemical analysis, is once a year (Department of Health 2007). The sanitation officer of the study area claimed that there is no regular monitoring of the physical and chemical quality of groundwater used for drinking in the municipality. That is because the analysis process of groundwater samples is costly and time-consuming; thus, the detection of possible groundwater contamination in the area might be difficult due to the monitoring inconsistency. Groundwater is an important source of water in rural areas worldwide such as in the case of Santa Ignacia; but published studies regarding groundwater quality in developing countries, such as the Philippines, are deficient. Consequently, this study was executed to provide baseline information for an upscale assessment and monitoring of groundwater quality in Santa Ignacia and other rural provinces in the Philippines that are substantially reliant on groundwater.

Conclusion

The spatial variation maps clearly showed that the quality of groundwater across sites of Santa Ignacia varied. The nitrite content of groundwater exceeded the permissible limit which indicates drinking water contamination. The high nitrite content may be associated with occurring agricultural activities in the area. Future health problems may arise if there will be a continued lack of regular monitoring of the physical and chemical quality of groundwater used for drinking in the

municipality. It is recommended to explore other significant groundwater quality parameters not included in this preliminary study. The identification of topographical features and existing anthropogenic activities in the municipality would also be significant in identifying the exact possible source of nitrite. The mentioned recommendations would be useful in establishing proper intervention to lessen groundwater contamination risk and to protect the groundwater sources. Furthermore, the populace of Santa Ignacia must be informed about the possible risk of consuming untreated groundwater.

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Declarations

Conflict of interest The authors have no conflict of interest to disclose.

Ethical approval The manuscript does not include issue related to ethical compliance.

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