A Geochemical Investigation and Review of Hydrogeology of The Dumaguete Aquifer

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Abstract

The unconfined nature of the Dumaguete aquifer and urbanization with mixed agricultural-commercial-industrial uses pose risks of groundwater contamination. Upland geothermal waters and the absence of municipal sewage treatment and landfill facilities add to such risks. Other contaminant sources include hydrothermally-altered volcanic rocks, septic tanks, sewer pipes, sewage ditches, polluted creeks, and subsurface saltwater lenses.

A review of hydrogeology and a geochemical investigation of the aquifer were conducted for this study. Samples from six barangays (five wells and a spring) were analyzed for temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), salinity, arsenic, cadmium, lead, mercury, nitrate, chloride, phosphate, sulfate, and ammonium. Coliform analysis was added. Statistical evaluation included kriging to map contaminant concentrations. Supplementary TDS, EC, and salinity data were collected from 22 wells and springs.

Higher levels of pH, TDS, EC, salinity, and sulfate were found in the northeast section of the city, with TDS exceeding regulatory standards in barangay Bantayan. Arsenic was borderline in Daro and detected in Batinguel. Chloride in Calindagan was an outlier (although below regulatory levels); nitrate levels exceeded standards at four sites; phosphate exceeded standards at all sites. High coliform counts were detected at three sites. Five sites had low DO levels. Groundwater monitoring and modeling are warranted for the sustainability of the aquifer.

Keywords: Dumaguete aquifer, Dumaguete hydrogeology, Dumaguete environmental, groundwater pollution, Dumaguete groundwater, groundwater physico-chemical characteristics, Dumaguete drinking water

Introduction

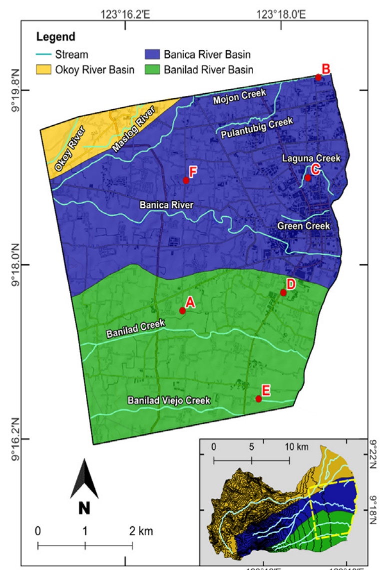
Background and Objectives

This paper was based on a senior thesis research conducted in 2023 and 2024 with partial funding from the Silliman University Angelo King Center for Research and Environmental Management (SUAKCREM). The main objectives were to characterize the Dumaguete aquifer via a review of the hydrogeology and groundwater sampling and to identify potential sources of contamination in the aquifer.

The term "geochemical investigation" is used herein to refer to the characterization of an aquifer based on natural chemical components and anthropogenic sources of potential pollutants. The term "Dumaguete aquifer" is defined herein to refer to the (>150-meter thick) unconfined aquifer that is the source of potable water in the municipality of Dumaguete. Such aquifer laterally extends into three adjacent municipalities and receives water from the Banica River basin, the Okoy River basin, and the Banilad River basin. The "Banilad River basin" is defined by two parallel creeks approximately 1.0 to 1.5 kilometers apart: the Banilad Creek and Banilad Viejo Creek. The three river basins cover Dumaguete and adjacent towns: Sibulan to the north, Valencia to the west, and Bacong to the south.

Figure 1

Map of the Dumaguete River Basins and Streams, Modified after SWECO/LWUA (2001) and Emmanuel (2017)



Note: Sampling sites are shown as red dots. The inset shows the complete extent of the river basins. Yellow dashed lines indicate the extent of Dumaguete City—additional data from Open Topo Map, NAMRIA, SRTM, and Dumaguete City Engineering Office.

Risks of contamination by anthropogenic sources are due to rapid urbanization and the historical and current land uses, including agricultural (e.g., farming, livestock production, meat processing), commercial, and industrial operations such as quarrying, packaging, construction, chemical and petroleum storage and distribution, printing, gas service stations, and vehicle repair. Additionally, there is a risk of contamination from thousands of old, leaky septic and sewer systems since the city has no sewage treatment facility. Many of these systems are decades old and are likely discharging into the soils and underlying aquifer. Gray water is mainly combined and discharged with stormwater via underground pipes and ditches (lined, unlined, covered, and open) into surface water and outfalls along the coast. Furthermore, there is the risk of surface- and groundwater contamination from the geothermal field in the uplands west of the city. Lastly, there has been concern that the Dumaguete dumpsite may have generated leachate that has contaminated the groundwater. Thus, since the Dumaguete aquifer is unconfined and consists of permeable sediments, potential contamination from various sources poses health risks to the community.

Previous Works

In the past few decades, most aquifer investigations have involved bacteriological analyses with some physicochemical analyses of well water. The results were rarely publicized or published. Geochemical and environmental investigations, including sampling for metals and organic compounds, were rare and focused on the potential impact of geothermal waters from the geothermal field in the uplands of Valencia on the alluvial plain underlain by the Dumaguete aquifer. Another historical area of interest for researchers was the Dumaguete dumpsite that operated in barangay Candau-ay from 1965 to 2021.

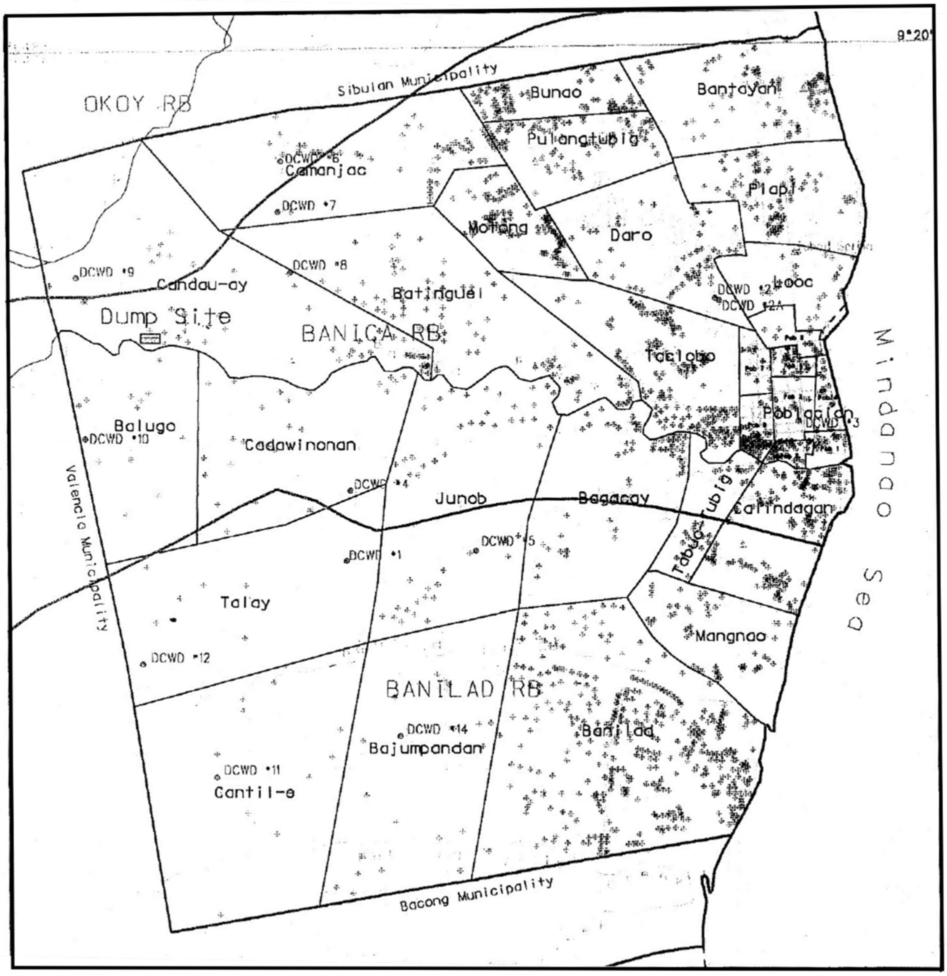
In 1994, the first significant groundwater study was reported by Geotecnica Corp., which conducted a hydrogeologic study of the Southern Negros Geothermal Field (SNGF), located on the uplands west of Dumaguete, and its geochemical and hydrogeologic impacts on the two major streams in the area (Okoy and Banica rivers) as well as the groundwater in the alluvial plain east and northeast of the SNGF.

SWECO (a Swedish engineering consulting firm) completed a subsequent groundwater study in collaboration with the Philippine Local Water Utilities Administration (LWUA) 2001. The report by SWECO-LWUA (2001) was submitted to the LWUA and the Dumaguete City Water District (DCWD). Such a report included a collection of available data on shallow and deep wells within the three river basins comprising the Dumaguete aquifer. It remains the most comprehensive hydrogeological study, which involved groundwater modeling of the aquifer. The SWECO study involved a compilation of data from around 16 public supply (deep production) wells, 1,736 public and private wells, and nine springs. SWECO completed the aquifer's first numerical groundwater modeling and simulation (using MODFLOW). Water supply scenarios for the next 30 years were presented. Despite such monumental compilation work, technical data from wells, such as construction details and water levels, are sparse. Only 25 wells had lithologic logs. Water-level histories were found from only 19 wells. Old chemical data (mostly 1980s and 1990s) on groundwater quality was available from only 67 wells. Analyses for most samples were for chloride, iron, manganese, hardness, and alkalinity. However, such technical data may not be reliable since it is missing QA/QC information, including detection limits and methodologies.

The last significant work was presented in a report by Caranto et al. (2006). They conducted elemental and isotope geochemistry to determine the relationship between the deep geothermal and shallow groundwater systems. The study involved 45 sources (shallow and deep wells, hot springs, cold springs, river water) sampled for various parameters from 1999-2002. Parameters included salinity, conductivity, temperature, oxygen-18 isotope, deuterium, tritium, CFC-11, CFC-12, CFC-113, and cations and anions (Cl, Br, Na, K, Li, and SO4). The relative ages of groundwaters in the Dumaguete aquifer were also determined using chlorofluorocarbon (CFC) data. Sampled water sources for CFC age dating included DCWD deep production wells (50-15 m) and other shallow wells (<50 m). For the age dating, five DCWD wells, six SNGF geothermal wells, and a creek were sampled. They also conducted numerical modeling of the groundwater system. Their model boundaries included only the Okoy and Banica river basins.

Figure 2

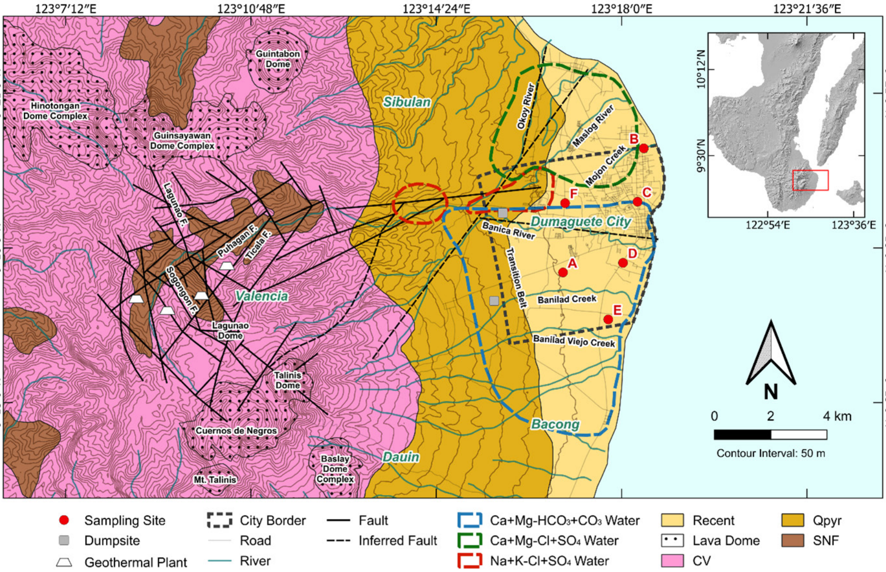
Public and Private Wells Inventoried by SWECO-LWUA (2001)



Note: "DCWD" wells were existing production wells as of 2001

Figure 3

Geologic Map of the SNGF-Dumaguete Area [modified after Antonio et al. (1976), Rae et al. (2004), Caranto (2005), Olivar & Apuada (2005), Caranto et al. (2006), Quinamot et al. (2015), and Ramirez (2016)]



Note: Red dots indicate sampling sites in Dumaguete City. Blue, green, and red dashed polygons indicate the areal extent of groundwater types from Caranto (2005). CV= Cuernos Volcanic Formation (Quaternary), Qpyr= Pyroclastic Deposits (Pliocene-Quaternary), SNF= Southern Negros Formation (Late Pliocene-Early Pleistocene). Base map data sources: NAMRIA, PhilGIS. Topographic contour interval 50 m.

Scope of Study

The Metro Dumaguete Water (MDW, formerly DCWD) regularly monitors the groundwater quality at their 16 pumping stations; however, analytical parameters only include total coliform, fecal coliform, and heterotrophic plate count (Emmanuel, 2017). Analytical results for additional parameters, if any, have not been published.

The investigation for this study involved sampling six randomly selected water sources: three domestic wells, one community well, one agricultural well, and one natural spring. The locations were spread out over the municipality's total area, at an average distance of 2.58 km apart. The land surface elevations at the six sites ranged from 5 to 43 m above Mean Sea Level (MSL). The estimated sampling depths at four wells ranged from 18 to 24 m below grade, while a fifth well was the deepest at 30 m. The spring in Banilad was, of course, at ground level.

Sampling was primarily performed in October and November of

2023. Analytical parameters included "analyze immediately" parameters (pH, temperature, dissolved oxygen or DO) as well as electrical conductivity (EC), total dissolved solids (TDS), and salinity using portable field instruments. A supplemental field survey was conducted from March 19 through 23, 2024. Random domestic wells and springs located mostly within the city's eastern half were sampled. A total of 20 wells and two springs were surveyed for field parameters: salinity, TDS, and EC.

Sample aliquots were sent to the laboratory for arsenic, cadmium, lead, mercury, chloride, nitrate, sulfate, phosphate, and ammonium analyses. The MDW lab and the Silliman University Chemistry Department performed the analyses. On March 9, 2024, supplementary sampling for bacteriological analysis was conducted. Lab analysis was performed in collaboration with biology students of Silliman University. The field readings and lab analytical results were evaluated using various statistical methods, presented in this report's Methodology, Results, and Discussion sections. A geostatistical evaluation consisted of Kriging and generating concentration isopleth maps for individual parameters.

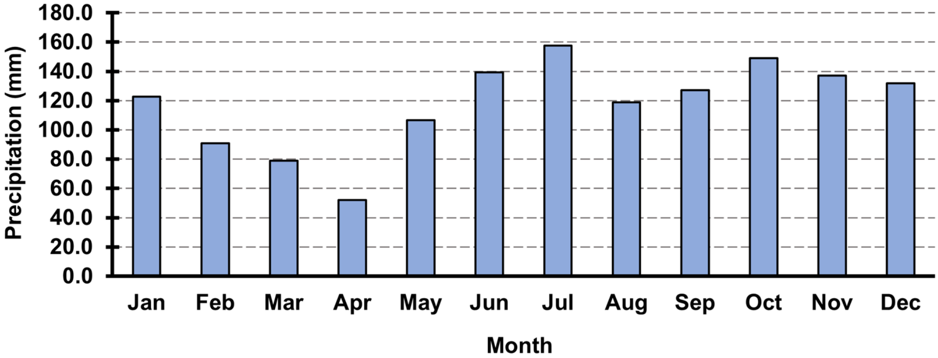
Physiography, Hydrology, and Hydrogeology of Dumaguete

Climate, Topography, and Soils

The Philippine archipelago has a tropical climate with relatively high temperatures, high humidity, and abundant rainfall. Only wet and dry seasons are experienced. Negros Island is classified as Type III in the Coronas Climate Classification used in the Philippines. As Type III, the area has one to three months of dry season from January to March with no pronounced maximum rain period from April through December (Caber & Rivera, 2023, PAGASA). Climate data from PAGASA (Dumaguete station) indicates that from 2004 to 2023, Dumaguete City had an average monthly air temperature of 28.1°C with an average minimum of 23.1°C and maximum of 33.0°C. The average annual precipitation was 1,412.2 mm. This is less than the average annual precipitation in the uplands (SNGF area) of 2,500 mm/yr. From 1991 to 2020, the average relative humidity was 81% annually, with the lowest percentage (79%) occurring in April and May and the highest percentage (84%) recorded in January.

Table 4

Average Monthly Precipitation at the Dumaguete Synoptic Station (2004-2023).



Source: PAGASA.

From the coastline, the land surface in Dumaguete slopes upward to the west and the neighboring town of Valencia (at 100 m above MSL), beyond which the elevations continue to rise towards the towering Cuernos de Negros, an inactive volcano (officially considered "potentially active" by PHIVOLCS). Viewing its topographic profile from afar, one can see that the city lies at the foot of the eastern concave slope of the volcano, which has a peak elevation of 1,900 m. The average gradient along the Dumaguete-Valencia Road is a steep 1.7%, while the gradient along the mainstem of the Banica River is slightly less at 1.5%.

Based on national soil classification nomenclature, Dumaguete is mantled by soils of the San Manuel-Taal Complex, San Manuel fine sandy loam, Dauin sandy loam, and Isabela clay. The following is a summary of soil distribution and descriptions from the report of Emmanuel (2017):

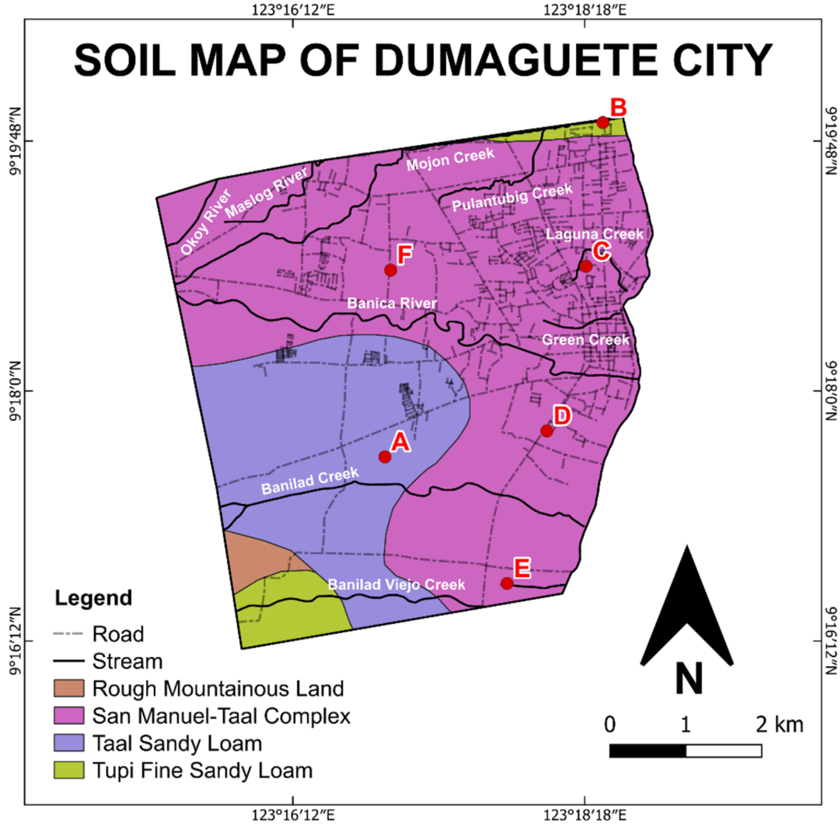
- San Manuel-Taal Complex: characterized by the San Manuel fine sandy loam and Taal sandy loam soils close to one another. It is distributed to the northwest of the city, is mostly sandy with large boulders on the surface, and with good drainage. This soil has been utilized for the cultivation of coconut trees and vegetables.
- San Manuel fine sandy loam: a kind of alluvium along the paths of rivers and creeks.
- Isabela clay: described as black, coarse, powdery, and loose. It tends to be sticky and plastic when wet. Its distribution is in barangays Looc, Piapi, and Bantayan.
- Dauin sandy loam: distributed to the east of the city, along the

coastline, with poor drainage and a shallow water table.

- Tupi fine sandy loam: distributed in a small area to the southwest of Dumaguete City

Figure 5

Map of the Soil Types in Dumaguete City [modified after Carmona & Ella (2022) according to the Bureau of Soils and Water Management]



Note: Sampling sites are shown as red dots. Soil definitions according to the Provincial Government of Negros Oriental (2011): San Manuel-Taal Complex is primarily sandy with good drainage and Taal soil found in the interior part of it; Taal Sandy Loam is water-laid volcanic soil around the eastern slope of Cuernos de Negros and is colored light gray to gray; Tupi Fine Sandy Loam is black, very friable and loose, with a fine granular structure to almost no structure, and the drainage is good. Other Data: Emmanuel (2017), Dumaguete City Engineering Office, NAMRIA, and PhilGIS.

Hydrology and Hydrogeology

Dumaguete falls within the Okoy, Banica, and Banilad watersheds (SWECO/LWUA, 2001). As a losing stream, the Okoy River contributes to the groundwater in the Dumaguete aquifer as it flows northeastward through the barangays of Candau-ay and Camanjac, then veers northward, continuing through the town of Sibulan (SWECO/LWUA, 2001) and discharging into the Tañon Strait. The Banica River is also a losing stream and runs eastward through the middle part of the city, including the barangays of Balugo, Cadawinonan, Junob, and Tinago, where it finally drains into the Bohol Sea (SWECO/LWUA, 2001).

Based on pre-2001 data, the mean annual rainfall in the Okoy watershed was estimated at 2,428 mm/yr, while that of Banica watershed was 2,147 mm/yr. The Okoy watershed has a direct runoff of 948 mm/yr, while the Banica watershed has a direct runoff of 664 mm/yr. Evapotranspiration is estimated at 1166 mm/yr for the Okoy watershed and 1161 mm/year for the Banica watershed. Net recharge for the two watersheds was estimated to be 314 mm/yr and 322 mm/yr, respectively (SWECO-LWUA, 2001).

The Banilad Creek, Banilad Viejo Creek, and Mojon Creek are smaller streams that also play a role in the hydrogeology of the Dumaguete aquifer. It is likely that they are predominantly losing streams but were noted to be gaining streams toward the east, near the coastline where springs are common. The tributaries of the Mojon Creek have not been accurately mapped. Mojon flows eastward through rapidly urbanized areas of barangays Camanjac, Pulantubig, Buñao, and Bantayan, where it discharges into the Bohol Sea (also known as Mindanao Sea). Likewise, the two Banilad creeks, located in the city's southern section, also flow eastward, through an increasingly urbanized area, toward the Bohol Sea.

Dumaguete is underlain by andesitic to dacitic volcaniclastics of the Quaternary age, which includes tuffaceous sandstone, shale, and conglomerate interbeds (SWECO/LWUA, 2001). The porous materials of the aquifer are characterized by permeable volcaniclastic layers from the surface down to 150 m (SWECO/LWUA, 2001). Such layers consist of unconsolidated to semi-consolidated sandy clays, sands, cobbles, and boulders, mainly from reworked volcanic pyroclastics and weathered flows. A limestone lens within the upper 25 m of the stratigraphic column and located approximately one kilometer from the coast was reported by Caranto et al. (2006); however, its extent and stratigraphy have not been defined. The limestone is reportedly coralline and occurs within the Quaternary alluvium.

No borehole stratigraphy, sedimentology, correlation to outcrops, and stratigraphic nomenclature have been established for the aquifer. For this study, the more than 150 m of sedimentary sequence likely correlates to the Pleistocene and Holocene formations– the Southern Negros Formation and the Cuernos Volcanic Formation. The limited limestone unit within the thick sequence of clastics may represent a brief marine transgressive event within predominantly alluvial fan and braided river environments. The "basement" rocks or the lower confining layer of the aquifer is unknown and has not been encountered in any deep well within the aquifer.

Figure 6

The Hydrogeologic Cross-section of the Dumaguete City Area [modified after Caranto et al. (2006)]

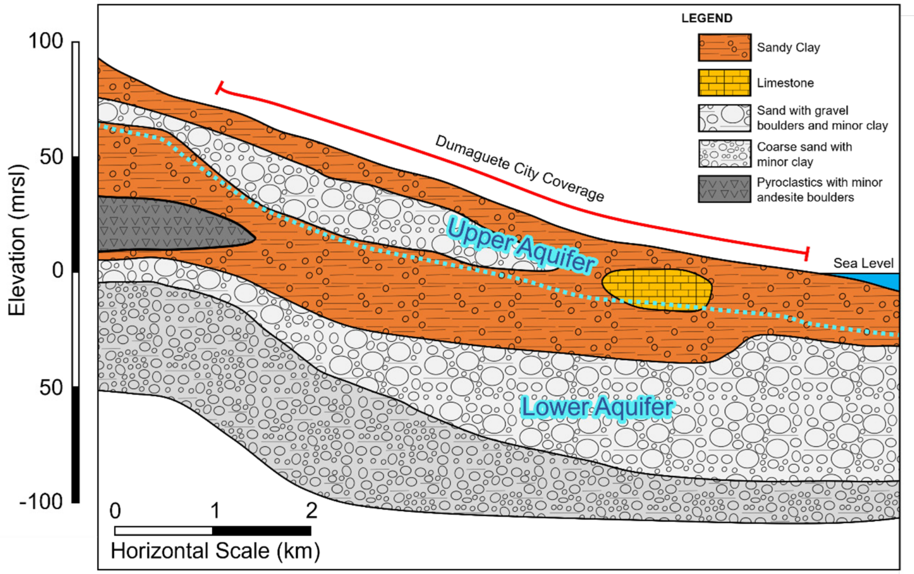
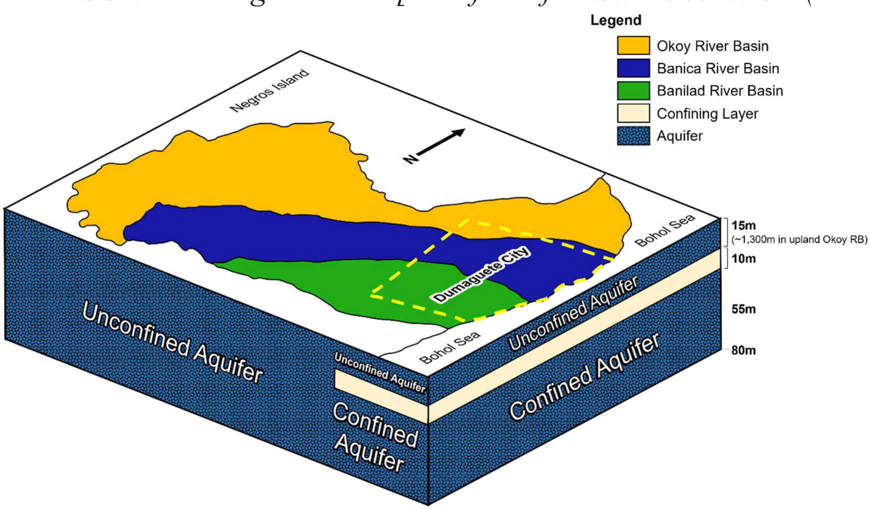


Figure 7

Block Diagram Suggesting of Groundwater Model of the Dumaguete Aquifer in the SGNF-Dumaguete Area [modified after SWECO/LWUA (2001)]



Note: Yellow dashed lines indicate the extent of Dumaguete City.

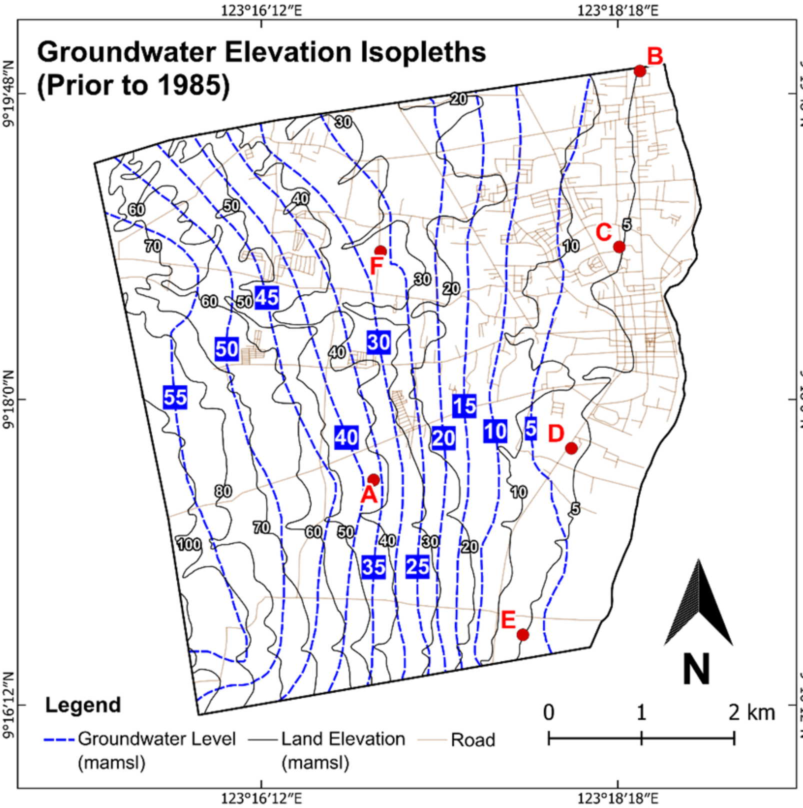
Groundwater in the aquifer originates from several sources. Vertical influx is from infiltration through precipitation and the losing streams of the Banica, Okoy, and Banilad rivers. There is also groundwater flux along the western municipal boundary due to lateral inflow from the upgradient and watershed areas of the Okoy and Banica rivers. Such lateral inflow has not been studied. Additionally, geothermal waters in higher elevations find their way into the groundwater via infiltration of hot spring waters (Caranto, 2005), although such contribution has not been quantified.

Groundwater flow is generally eastward and perpendicular to the coast (Geotecnica, 1994; Caranto, 2005). This is obvious when examining the land surface contours on a topographic map. Caranto (2005) noted that the water table occurred about 70 m below grade in the Palinpinon (Valencia) area. This is much lower than earlier reports of a high water table or potentiometric surface, including artesian conditions in this area in the 1970s (Geotecnica, 1994). Due to the recent installation of public water supply wells in the past several years, including the latest PS-21 well completed by MDW in March 2024, water levels are now presumed to be lower than 2005 levels. Cones of depression are likely developing around the actively pumping wells.

SWECO/LWUA (2001) noted that the elevation of the water table was zero near the coast, rising to 55 m above MSL at the contact between the plains and foothills ("transition belt" of reworked pyroclastic deposits located about 5 km from the coastline). Pre-1985 groundwater contours (from SWECO-LWUA, 2001) superimposed on land surface contours show shallow to above-ground water (artesian) levels in the southeast section of the city (Figure 8). Fieldwork during this study confirmed that specific locations along the city's eastern part have a water table higher than the stream stage, resulting in springs and gaining stream conditions.

Figure 8

Groundwater Elevation Isopleth Map of Dumaguete City before 1985 [modified after SWECO/LWUA (2001)]



Note: Sampling sites are shown as red dots—additional data from NAMRIA and PhilGIS.

Intercalations of less permeable clayey layers, particularly along the coast, have reportedly resulted in local artesian conditions. Such a laterally limited confining layer with an underlying "artesian aquifer" of a limited extent was modeled by SWECO/LWUA (2001) in their groundwater model and simulation (Figure 7). Fieldwork for this study, however, did not find flowing artesian wells but rather only surficial springs, which are a result of either seepage faces or subsurface fractures and faults that act as pathways for upward-flowing artesian groundwater from the deeper, confined part of the aquifer.

The hydrogeologic cross-section of Caranto et al. (2006) depicts an "upper" and a "lower" aquifer (Figure 6); however, there is no detailed description of the two apparent aquifers, the confining layer, and water levels. Instead, Caranto (2006) reports that the uniformity of chemical and isotope characteristics of the groundwater indicates a single unconfined aquifer with occasional lenses of clay. At this point, the model by SWECO/LWUA of a confining clay layer (between a lower confined aquifer and an upper water table aquifer) at a depth of 15 m, with a thickness of 10 m, and a limited lateral extent (one km wide) along the eastern part of the city

(Figure 7) seems more plausible. Additional hydrogeologic investigation is warranted.

The total annual groundwater potential as of 2001 was estimated to be 50,615 cubic meters per day (cum/d) and includes 18,682 cum/d from direct recharge and 31,933 cum/d from lateral inflow from the upland areas of the Banica River basin. In 2001, the total withdrawal from the aquifer was 21,826 cum/d. The predicted withdrawal rate in 2030 was estimated at 40,167 cum/d (SWECO/LWUA, 2001).

The Okoy and Banica rivers are major contributors to the "shallower groundwaters" in the aquifer (Caranto, 2005). At the "transition belt" of reworked pyroclastic deposits, the groundwater levels range from 40 to 60 m below the river bottoms. However, the groundwater levels on the plains are only a few meters below the river bottoms. River water seepage into the surrounding permeable sediments makes the Okoy and Banica rivers highly influential near the porous transition belt (SWECO/LWUA, 2001) and towards the plains. Both rivers can be classified as losing streams along much of their mainstems; thus, contaminants would find their way into the groundwater. A similar condition presumably occurs in the Banilad River basin.

Toward the coastline, where the water table is shallow, Okoy, Banica, and the two Banilad rivers appear to be gaining streams. The exact points along the rivers where the streams become gaining or losing have not been studied.

Significant Findings of Previous Works

Groundwater Investigations

The Dumaguete aquifer is influenced by the outflowing geothermal waters from the SNGF via groundwater recharge from surficial hot springs (Caranto, 2005). The resulting mixture of the geothermal and meteoric waters in the aquifer has resulted in three chemical groundwater types, namely $Na+K\text{-}Cl+SO_4$ waters (hot spring origin), $Ca+Mg\text{-}HCO_3+CO_3$ waters ("typical" meteoric) and $Ca+Mg\text{-}Cl+SO_4$ waters (typical waters mixed with hot spring waters) as shown on the map in Figure 3 (modified from Caranto, 2005). In and around the barangays of Junob and Cadawinonan, "deep" groundwater is described as typical (meteoric water), while deep groundwater under the Batinguel and Candau-ay area is relatively chloride-rich and influenced by both Okoy and Banica rivers (Caranto, 2005). It is noted, however, that there is no clear definition of "deep" and "shallow" groundwater. Northeast of the geothermal plant (i.e., within the Okoy River basin), the groundwater is characterized as "typical" (meteoric) water mixed with hot spring waters based on isotopic and elemental chemistry (Caranto, 2005).

According to SWECO/LWUA (2001), six wells sampled in the Okoy and Banica river basins and one near Banica River yielded relatively high chloride contents ranging from 110 to 303 mg/L. The chloride source was considered "unknown" since the wells were located too far inland (SWECO/LWUA, 2001) away from the coast and seawater. Later work by Caranto (2005) suggested that geothermal waters are a source of chloride. The SWECO/LWUA (2001) report also presented available annual sampling results from 67 wells between 1983 and 1994; up to 10 wells had various iron, manganese, mercury, and arsenic detections, some exceeding "permissible limits." However, there was no additional discussion of the results and "permissible limits."

The "shallow" and "deep" aquifers (upper and lower parts of the single aquifer?) are recharged mainly during the rainy season, with little to no recharge during the dry season, according to isotopic data. Historical pumping tests by the DCWD indicated higher hydraulic conductivities in shallow wells and slightly lower hydraulic conductivities in deeper wells (Caranto, 2005). This would be expected from increasing compaction and lithification of the sediments with depth. The average hydraulic conductivity values obtained from pumping the shallow and deep wells were 0.00025 and 0.00005 m/s, respectively. Transmissivity values ranged from 1.91 to 0.0301 m2/s for the deeper wells (Caranto, 2005).

Impact of Dumpsite

The city dumpsite was established in 1965, with an area of 2.3 hectares in barangay Candau-ay, about five kilometers from downtown. The dumpsite had not been adequately designed, and there were no essential components such as a liner, daily cover, flood control, odor control, landfill gas collection system, leachate collections system, or groundwater monitoring system. By 2010, accumulated waste piles were estimated at 84,000 m3, with unsegregated waste from households and commercial and industrial establishments (Emmanuel, 2017).

The dumpsite was situated along the Banica River and about a few hundred meters from housing projects. Water flooding into the dumpsite was reported to occur during heavy rainfall, which raised concerns about groundwater contamination. The water table was about 5 to 12 m below the surface, separated from contact with the waste materials by the moderately to highly permeable San Manuel-Taal Complex, making possible the leaching of contaminants into groundwater. Hydrogen sulfide and ammonia were contributors to the foul smell; methane and carbon dioxide were among the notable greenhouse gases emitted in the place (Emmanuel, 2017). Chemical and biological testing of leachate (discharging from the side of the mound and into the Banica River) 2010 revealed a high BOD of 5,128 mg/L. Total suspended solids (TSS) were also at 846.7 mg/L and nitrate at 1.06 mg/L. BOD was also measured from the Banica River water upstream and downstream of the dumpsite area, and higher concentrations were revealed downstream by more than double, from 0.69 mg/L upstream to 1.51 mg/L downstream (Emmanuel, 2017).

In 2010, soil samples collected from the dumpsite had a maximum lead content of 72.9 mg/kg and cadmium at 58.9 mg/kg. The acceptable level of lead was <80 mg/kg and cadmium was <1.7 mg/kg (Emmanuel, 2017). Thus, cadmium significantly exceeded the acceptable limit, while lead was close to its corresponding acceptable limit.

It was postulated that groundwater underneath the dumpsite is contaminated by leachate, with likely high BOD, coliform, inorganic pollutants, heavy metals, and other organic contaminants (Emmanuel, 2017). The city's current water purveyor, MDW, has four pumping stations near the dumpsite, which could be impacted by potential contamination. Three of these (Pumping Stations 9, 10, and 18) are upgradient of the facility, while Pumping Station 8 is 1,000 m downgradient and more vulnerable to contamination by any leachate (SWECO/LWUA, 2001; Emmanuel, 2017).

In the past several years, there have been continuing indications of leachate outflowing directly into the Banica River (Emmanuel, 2017). Recent work by Romo (2024) confirms that leachate seeps out of the dumpsite mound and into the Banica River. Since the Banica is a losing stream, contaminants are likely impacting the groundwater.

S.U. biology student F. Romo conducted the last known groundwater investigation of the dumpsite as part of her senior thesis (Romo, 2024). Romo sampled the leachate from the mound and seven water supply wells closest to the dump site. Her samples were analyzed for bacteria, pH, electrical conductivity, DO, biochemical oxygen demand (BOD), ammonium, phosphate, sulfate, cadmium, and lead. Romo (personal communication, March 2024) indicated that phosphate (at four sites) and ammonium (at three sites) were detected at concentrations exceeding the Department of Environment and Natural Resources (DENR) standards. In reviewing her results, it was noted that DO levels were all out of compliance, below the minimum 5 mg/L, which was the DENR's criterion for Class AA waters. Similarly, BOD levels at four sites exceeded the 1.0 mg/L DENR criterion for Class AA waters. Such exceedances suggest that a leachate plume has developed and contaminated the aquifer.

Besides the MDW, over a thousand households, communities, and establishments independently extract groundwater from wells. These are also vulnerable to groundwater contamination from the leachate (Emmanuel, 2017).

Methodology

Sampling Sites

For this study, five water supply wells and one spring (a total of 6 sites in 6 barangays) were chosen for random sampling of groundwater in late 2023. (See Figure 9 for photos and Figures 1, 3, 5, and 8 for maps of the sampling sites.) Site A in Junob has an abandoned domestic well temporarily used by construction workers. (The contractor and site owner have requested anonymity.) Two of the wells are owned by Silliman University (S.U.), with one used for agricultural water supply located in Silliman Farm in Bantayan (Site B) and the other (Site C) serving as a community well for several dormitories and other buildings within the university campus (such area being part of Daro). Site D has a domestic well in Calindagan. Site E is a natural spring used by the local community in Banilad. Site F has a domestic well in a predominantly residential area along Boni Catarata Street in Batinguel. At around the same time but under a separate study, S.U. biology student F. Romo sampled this 60 ft well. Her sample was designated "GW-6" and analyzed for similar parameters, except for arsenic, mercury, nitrate, and chloride, which were all analyzed for this study. Table 1 below summarizes the information on the sampling sites.

Table 1

Information on Sampling Sites and Groundwater Sources Sampled and Their Assigned Labels

Sampling Site	A	B	C	D	E	F
Location (Barangay)	Junob, Dumaguete City	Bantayan, Dumaguete City	Daro, Dumaguete City	Calindagan, Dumaguete City	Banilad, Dumaguete City	Batinguel, Dumaguete City
Address	Jose Romero Road	Hibbard Avenue	Aldecoa Drive	Lamberto Macias Road	Santa Monica Road	Boni Catarata Street
Source Type	Well	Well	Well	Well	Spring	Well
Latitude	9°17'31.52"	9°19'55.99"	9°18'53.86"	9°17'42.72"	9°16'36.83"	9°18'52.18"
Longitude	123°16'51.69"	123°18'25.84”	123°18'18.55"	123°18'1.63"	123°17'44.46"	123°16'54.17"
Elevation	43 MAMSL	5 MAMSL	5 MAMSL	6 MAMSL	5 MAMSL	33 MAMSL
Depth (est.)	18.2 m	24.3 m	30.4 m	18.2 m	N/A	18.2 m
Pump Type	Hand Pump	Centrifugal Pump	Submersible Pump	Hand Pump	Free flowing	Hand Pump
Average Discharge	0.117 L/s	0.252 L/s	1.287 L/s	0.078 L/s	0.266 L/s	0.057 L/s
Usage	Former domestic	Agricultural	Community	Domestic	Community	Domestic
Year Installed (circa)	1993	1950	2001	1970	N/A	1970
Owner	N/A (Abandoned)	Silliman University	Silliman University	Mrs. Enriqueta Aranas	Mrs. Georgina Villahermosa	Mrs. Rustica Baylon
Remarks	Construction site. Well, to be decommissioned.	Approximately 10 m from Mojon Creek and a natural spring	Approximately 90 m from Laguna Creek. Supplies water to dorms and buildings	The owner previously reported bacterial contamination.	Enclosed in concrete tank with metal and PVC pipes as outlets.	Pumped dry at 20 and 40 ft. Completed at 60 ft.

MAMSL= meters above mean sea level. N/A= not applicable.

Figure 9
Photos of the Groundwater Sources Sampled: (A) Junob, (B) Bantayan, (C) Daro, (D) Calindagan, (E) Banilad, and (F) Batinguel.

Analytical Parameters

The water samples from each site were analyzed for field parameters: temperature, salinity, TDS, pH, EC, and DO, and for lab analytes: arsenic, cadmium, lead, mercury, chloride, nitrate, sulfate, phosphate, and ammonium. Bacteria, such as total coliform and fecal coliform, were later added to the scope of work. All parameters except for cadmium, lead, ammonium, phosphate, and sulfate were analyzed for Site F. Data for the exceptions was instead obtained from the work of biology student F. Romo, who sampled the same well (but named it "GW-6") for similar parameters around the same time.

Preparation of Field Instruments

All necessary calibrations of the field instruments followed the manufacturer's protocols before fieldwork. The Extech ExStik EC500 conductivity and pH sensors were calibrated first, followed by the Extech ExStik DO600. Procedures outlined in the manufacturer manuals were closely followed. The EC500's electrode was calibrated by submerging it into three standardizing solutions (84, 1413, and 12,880 μS/cm). The pH electrode was calibrated using a 3-point method by separately immersing it in pH 7, pH 4, and pH 10 buffer solutions to ensure accuracy. Calibration of the DO600 was calibrated each day of field use by turning it on and leaving it idle while displaying the % measurement unit for three minutes until it fully polarized.

Preparations at the Sampling Site

Under USEPA protocols, the water supply wells were pumped for at least 15 minutes to evacuate stagnant water and purge the volume of water in the well casing and intake pipe to ensure the collection of fresh samples that represent actual groundwater conditions. The natural spring in barangay Banilad was directly sampled since water continuously flows from the discharge pipe of a concrete enclosure.

Analyzing Field Parameters

The EC500 and DO600 were used at each site to analyze field parameters, including the "analyze immediately" parameters: pH, temperature, and DO. Other field parameters included salinity, TDS, and EC. A plastic sample cup pre-rinsed with distilled water was conditioned five times using well water before filling it to a volume of 20 ml for submerging the instruments' electrodes. For DO readings using the DO600, the electrode was continuously and gently stirred in the sample cup until a stable reading was achieved and recorded. Three trials were performed at each sample location. Following each trial, the electrode was rinsed with distilled water and then patted dry with dedicated tissue in preparation for the subsequent trial measurement.

Similarly, the EC500 was prepared by rinsing the electrode with distilled water. The electrode was then patted dry using tissue, submerged into the sample cup, and briefly stirred to remove air bubbles. Readings were then noted in the following sequence: temperature in °C, pH in standard pH units, salinity in ppm, TDS in ppm, TDS in mg/L, and EC in μS/cm. Afterward, the electrode was rinsed again with distilled water, patted dry with tissue, and set aside on a fresh, clean piece for the subsequent trial.

Sampling for Lab Analysis

After purging the well at each site, sample aliquots were collected in a 1-liter sterilized plastic sample bottle provided by Metro Dumaguete Water (MDW) Laboratory and in a 500 mL plastic distilled water bottle for the S.U. Chemistry lab. The sample jars were conditioned or rinsed five times with well water before collecting a final sample. The jars were then labeled and stored in a cooler with ice packs for preservation during transport. While rinsing the 1-liter jar, the well's pumping rate was also determined by noting the time needed to fill up the jar. This involved three trials, which were averaged. Immediately following sample collection, the samples were submitted to the two labs. The 1-liter jars were submitted to MDW Laboratory, while the 500 mL jars were submitted to Dr. M. Cerdania of the S.U. Chemistry Department.

Lab Analytical Methodologies

The MDW Laboratory performed the analysis of arsenic, cadmium, and lead using electrothermal atomic absorption spectrometry (AAS); mercury using hydride generation-AAS; nitrate via UV spectrophotometric screening; chloride via argentometry; sulfate via nephelometry; and phosphate via the ascorbic acid molybdo-tartrate ascorbic acid method. M. Cerdania of the S.U. performed an analysis for ammonium. Chemistry Department using the Salicylate Hypochlorite method.

Table 2 below summarizes the analytical methodologies for this study. Only field parameters and arsenic, mercury, nitrate, and chloride were analyzed for Site F. The other analytical data for Site F were obtained from the study by Romo (2024), who sampled the same well (designated Site F for this study, but "GW-6" for her study) during the same period.

Table 2

Analytical Methods, Venues, and Analysis

PARAMETER	ANALYTICAL METHOD	LOCATION	ANALYST(S)
Temp.	ExStik EC500 Digital thermometer	In-Situ	Researcher
pH	ExStik EC500 (Proprietary)	In-Situ	Researcher
EC	ExStik EC500 (Proprietary)	In-Situ	Researcher
TDS	ExStik EC500 (Proprietary)	In-Situ	Researcher
Salinity	ExStik EC500 (Proprietary)	In-Situ	Researcher

DO	ExStik DO600 (Proprietary)	In-Situ	Researcher
As	Electrothermal-AAS	MDW Laboratory	MDW Laboratory
Cd	Electrothermal-AAS	MDW Laboratory	MDW Laboratory
Pb	Electrothermal-AAS	MDW Laboratory	MDW Laboratory
Hg	Hydride Generation-AAS	MDW Laboratory	MDW Laboratory
NO3-	UV Spectrophotometric Screening	MDW Laboratory	MDW Laboratory
Cl-	Argentometry	MDW Laboratory	MDW Laboratory
PO4-3	Ascorbic Acid Molybdo – Tartrate Ascorbic Acid Method	MDW Laboratory	MDW Laboratory
SO4-2	Nephelometry	MDW Laboratory	MDW Laboratory
NH4+	Salicylate Hypochlorite	S.U. Chemistry Laboratory	Dr. Melchor Cerdania
TC	Membrane Filtration and Incubation at 37 °C	S.U. Biology Laboratory	Dr. Robert Guino-o, biology students, and the researcher
FC	Membrane Filtration and Incubation at 44 °C	S.U. Biology Laboratory	Dr. Robert Guino-o, biology students, and the researcher

Temp.= temperature, EC= electrical conductivity, TDS= total dissolved solids, DO= dissolved oxygen, As= arsenic, Cd= cadmium, Pb= lead, Hg= mercury, NO_3^- = nitrate, Cl- = chloride, PO_4^{-3} = phosphate, SO_4^{-2} = sulfate, NH_4^+ = ammonium, TC= total coliform, FC= fecal coliform, AAS= atomic absorption spectrometry, UV= Ultraviolet, MDW= Metro Dumaguete Water, SU= Silliman University.

Results

The analytical results were compared to the Department of Health (DOH) Drinking water standards and the DENR water quality guidelines for Class A and AA water bodies. Additionally, international standards and criteria (for drinking water) of the World Health Organization (WHO) and the U.S. Environmental Protection Agency (USEPA) were used for the evaluation of specific results. The purpose of the multiple references was to compare the results to the most stringent standards and criteria. These are presented in Table 3 below. These standards (enforceable) and criteria or guidelines (non-enforceable) are hereafter variably referred to as "referenced thresholds," "referenced standards," "referenced criteria," or "referenced limits."

Table 3

Water Quality Standards from Multiple agencies, including the Department of Health (DOH), Department of Environment and Natural Resources (DENR), World Health Organization (WHO), and United States Environmental Protection Agency (USEPA)

PARAMETER	PNSDW (DOH, 2017)	WQG - Class A (DENR, 2016, 2021)	GDWQ (WHO, 2011, 2022)	NPDWR (USEPA, 2009)	Unit
Temp.	-	26–30	-	-	°C
pH	6.5 – 8.5	6.5 – 8.5	6.5 – 8.5	6.5 – 8.5	pH units
EC	-	-	1500	-	µS/cm
TDS	600	-	600	500	mg/L
Salinity	-	-	-	-	
DO	-	5 (minimum)	-	-	mg/L
As	0.01	0.01	0.01	0.01	mg/L
Cd	0.003	0.003	0.003	0.005	mg/L
Pb	0.01	0.01	0.01	0.015	mg/L
Hg	0.001	0.001	0.006	0.002	mg/L
NO_3-	50	7	50	10	mg/L
Cl^-	250	250	250	250	mg/L
PO_4^{-3}	-	0.025	-	-	mg/L
SO_4^{-2}	250	250	250	250	mg/L
NH_4^+	-	-	35	-	mg/L
TC	< 1	-	0	0	CFU/100 mL
	< 1.1	-	0	0	MPN/100 mL
FC	< 1	-	0	0	CFU/100 mL
	< 1.1	50	0	0	MPN/100 mL

Temp.= temperature, pH= potential of hydrogen, EC= electrical conductivity, TDS= total dissolved solids, DO= dissolved oxygen, As= arsenic, Cd= cadmium, Pb= lead, Hg= mercury, NO_3^- = nitrate, Cl- = chloride, PO_4^{-3} = phosphate, SO_4^{-2} = sulfate, NH_4^+ = ammonium, TC= total coliform, FC= fecal coliform, CFU= colony forming units, MPN= most probable number, N/A= not applicable, (-)= no information. PNSDW= Philippine National Standards for Drinking Water. WQG= Water Quality Guidelines. Class A= Water bodies intended as water supply sources requiring conventional treatment to meet the latest PNSDW. GDWQ= Guidelines for Drinking-Water Quality. NPDWR= National Primary Drinking Water Regulations.

The health risks associated with the pollutants addressed in this study are summarized in Table 4 below. The parameters of this study were based on their common occurrence in groundwater (from the review of literature), occurrence in geothermal fields, and detection in historical sampling of wells in the area. Other factors were considered when selecting the parameters, namely, the analytical cost and budget constraints for the senior thesis study and the limitations in the analytical capabilities of the laboratories in Dumaguete. For example, the local laboratories are currently incapable of analyzing volatile organics, PAHs, pesticides, herbicides, and PCBs.

Table 4

Typical Problems Arise from Contaminants in Domestic Water Supplies (Litke, 1999; USEPA, 2009; Tchounwou et al., 2012; WHO, 2011, 2022; NJDOH)

PARAMETER	POTENTIAL HEALTH AND OTHER EFFECTS
pH	Corrosion of equipment
Total Dissolved Solids (TDS)	Unpalatable water, scaling in equipment
Arsenic (As)	Damage to skin and circulatory system, carcinogen, death
Cadmium (Cd)	Kidney damage, organ irritation, poisoning, death
Lead (Pb)	Neurological problems, kidney damage, high BP, carcinogen
Mercury (Hg)	Kidney damage, toxicity, allergic reactions, corrosion
Nitrate (NO_3^-)	Blue-baby syndrome, illness, shortness of breath, death
Chloride (Cl^-)	Salty taste, corrosion of equipment
Phosphate (PO_4^{-3})	Eutrophication (growth of algae)
Sulfate (SO_4^{-2})	Laxative, dehydration, corrosion
Ammonium (NH_4^+)	Chlorine reactions, respiratory problems, irritation or burns
Coliform Bacteria	Diarrhea, cramps, nausea, headaches, or other symptoms

Field Parameters

The line graphs in Figure 10 show the results for field parameters (pH, temperature, DO, salinity, EC, and TDS). Site B (Bantayan) had the highest values for these parameters, while Site E (Banilad) exhibited the lowest. Sites C and D approached the maximum contaminant level (MCL at 500 mg/L) for TDS as defined by the USEPA (2009). Site B exceeded the MCL set by the USEPA (2009) and the 600 mg/L limit set by the DOH

(2017) and the WHO (2011, 2022). Sites A (Junob) and F (Batinguel), situated at higher elevations toward the west, exhibited significantly lower readings of such parameters.

For temperature, it was noted that Site D (Calindagan) had the highest temperature reading (32.6 0C). The same site had the lowest DO reading at 3.32 mg/L. All sampling sites, except Site F, had non-compliant DO levels below the 5 mg/L DENR minimum limit or water quality guideline for Class A water bodies (DENR 2016, 2021). Site F had a DO of 5.13 mg/L, which barely passed the DENR limit. DO is typically inversely proportional to water quality; thus, a low DO level indicates polluted water.

The concentration isopleth maps for field parameters pH, EC, TDS, and salinity show a consistent trend of increasing concentrations toward the northeast, with the highest results found at Site B (Bantayan). These four parameters were highly correlated in the Pearson product-moment correlation matrix.

In comparing the results with regulatory standards and criteria, Site B was found to have TDS (at 703 mg/L) exceeding the 500 mg/L MCL of the USEPA (2009), the 600 mg/L limit of the DOH (2017), and the 600 mg/L limit of the WHO (2011, 2022). Sites C and D approached the USEPA limit of 500 mg/L (see graph, Figure 10).

Ions and Coliform Bacteria

Nitrate had elevated concentrations at four sites-- A, C, E, and F-- which exceeded DENR (2016, 2021) and USEPA (2009) limits. The concentration isopleth map for nitrate suggests an increasing trend from east (coastal areas) to west (uplands). Chloride concentrations were all below the referenced limit of 250 mg/L. In five samples, chloride was low and ranged from 14.4 to 46.9 mg/L, while the sample from Site D (Calindagan) had the highest chloride at 181 mg/L, which was determined as an outlier (based on the 1.5 IQR test) as shown on the box and whisker plot (Figure 14). Such chloride outlier suggests proximity to a contaminant source, such as a nearby leaky septic tank or the frequently ponded (with sewage water) area near the well. The possibility of saltwater influence is presented in the Discussion section of this report. This relatively high chloride level may explain the non-detect bacterial count (salty solution inhibiting bacterial growth) at Site D, as suggested by the negative correlation between chloride and bacteria in the Pearson product-moment correlation chart.

Phosphate at all sites exceeded the DENR (2016, 2021) limits, having concentrations ranging from 0.13 to 0.45 mg/L. Sites B and D (Bantayan and

Banilad, respectively) had the highest concentrations (0.42 to 0.45 mg/L),which may be attributable to the historical agricultural land use at Site B and a mixed residential and farming use of the land around Site D.

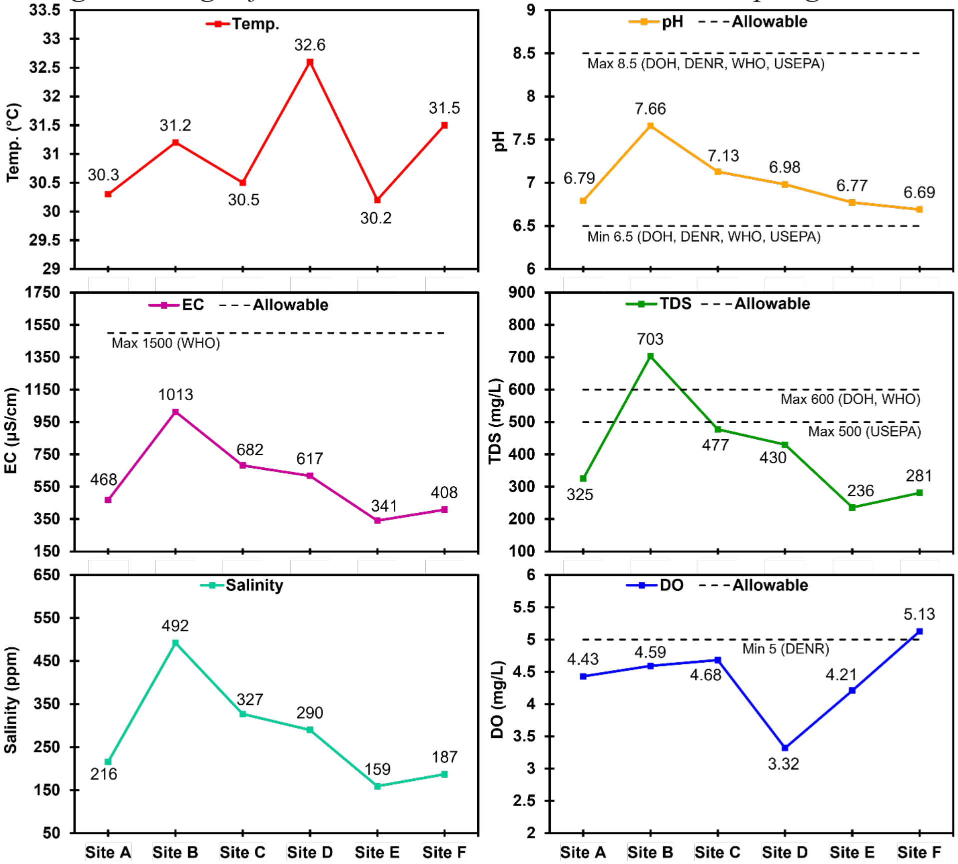
Total coliform (TC) bacteria at Sites A, C, and E exceeded the maximum threshold of <1 Colony-Forming Unit (CFU)/100 mL recommended by the DOH (2017). Site B had seemingly low (4 CFU/100 mL) but non-compliant TC levels. Sites D and F had no TC presence, although one of the three trials from the Site F sample resulted in trace amounts of fecal coliform (FC). TC was highly correlated with nitrate in the Pearson product-moment correlation matrix (Figure 13).

Heavy Metals

Lab analysis of heavy metals revealed generally compliant concentrations across all six sites. Arsenic concentrations were within the acceptable limit (0.01 mg/L) at all sites; however, Site C (Daro) had an elevated concentration of 0.009 mg/L, which is borderline. Cadmium and lead were not detected above their detection limits (0.001 mg/L and 0.003 mg/L, respectively) at any site except Site A (Junob), where a trace amount of cadmium (0.001 mg/L) was detected. Such cadmium level is compliant with water quality standards. Mercury was not detected across all sites, with a detection limit (0.001 mg/L) that coincides with the regulatory limit established by the DOH (2017) and DENR (2016, 2021).

Figure 10

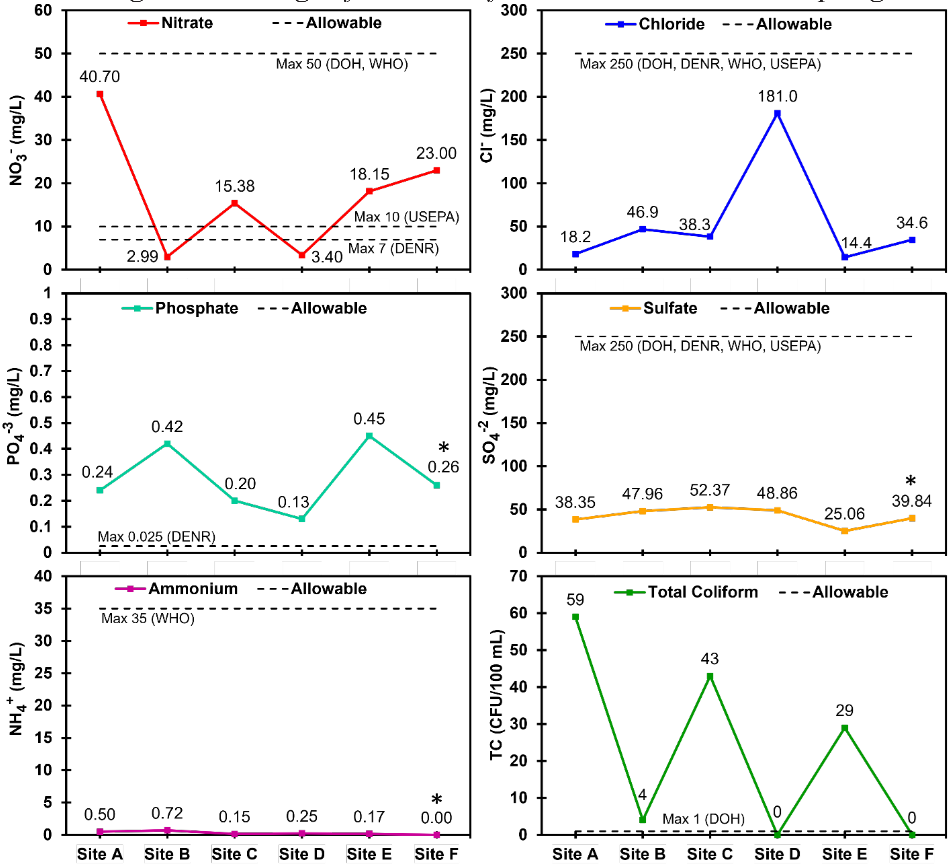
Average Readings of In-situ Field Parameters at Each Sampling Site.



Temp.= temperature, EC= electrical conductivity, TDS= total dissolved solids, DO= dissolved oxygen, Max= maximum, Min= minimum. For regulated parameters, the maximum/minimum allowable concentrations are indicated along with the authorities that established the standards (i.e., USEPA, 2009; DOH, 2017; DENR, 2016, 2021; and WHO, 2011, 2022).

Figure 11

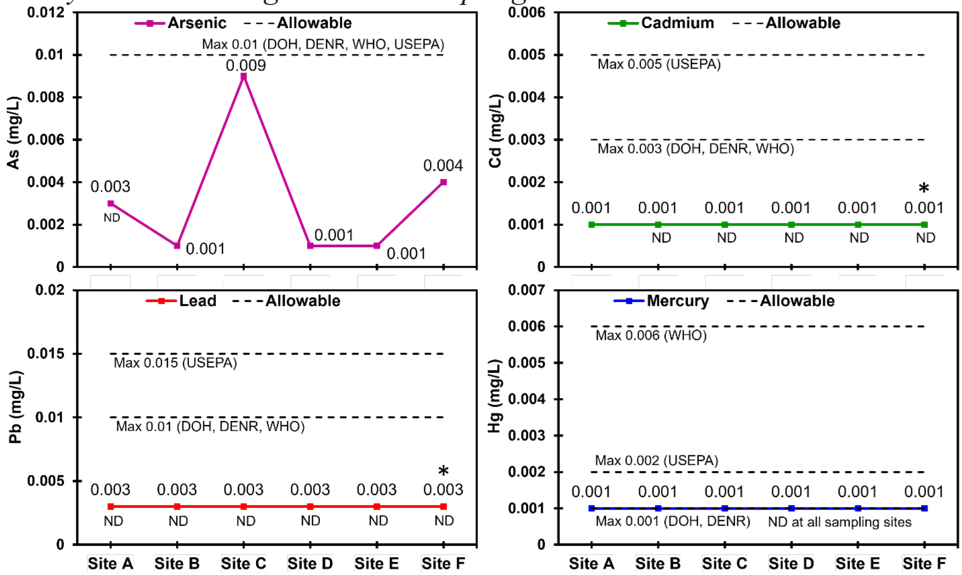
Ion Readings and Average of Total Coliform Results at Each Sampling Site.



NO_3^- = nitrate, Cl^- = chloride, PO_4^{-3} = phosphate, SO_4^{-2} = sulfate, NH_4^+ = ammonium, TC= total coliform, (*)= indicates data obtained from Romo (2024). The maximum allowable concentrations are indicated for regulated parameters, along with the authorities that established the standards (i.e., USEPA, 2009; DOH, 2017; DENR, 2016, 2021; and WHO, 2011, 2022).

Figure 12

Heavy Metal Readings at Each Sampling Site



As= arsenic, Cd= cadmium, Pb= lead, Hg= mercury, ND= non-detect, (*)= indicates data obtained from Romo (2024). The maximum allowable concentrations and the authorities established the standards (i.e., USEPA, 2009; DOH, 2017; DENR, 2016, 2021; and WHO, 2011, 2022) are indicated.

Figure 13

Pearson Product-moment Correlation Matrix of Parameters

	Temp.	pH	EC	TDS	Sal.	DO	As	NO_3^-	Cl^-	PO_4^{-3}	SO_4^{-2}	NH_4^+	TC	FC
Temp.		0.1	0.2	0.2	0.2	-0.5	-0.3	-0.6	0.9	-0.5	0.5	-0.1	-0.8	0.2
pH	0.1		1.0	1.0	1.0	0.0	-0.1	-0.6	0.1	0.3	0.6	0.7	-0.2	-0.4
EC	0.2	1.0		1.0	1.0	0.0	0.0	-0.6	0.2	0.1	0.7	0.7	-0.3	-0.4
TDS	0.2	1.0	1.0		1.0	0.0	0.0	-0.6	0.2	0.1	0.7	0.7	-0.3	-0.4
Sal.	0.2	1.0	1.0	1.0		0.0	0.0	-0.6	0.2	0.1	0.7	0.7	-0.3	-0.4
DO	-0.5	0.0	0.0	0.0	0.0		0.5	0.4	-0.8	0.3	-0.1	-0.1	0.1	0.6
As	-0.3	-0.1	0.0	0.0	0.0	0.5		0.2	-0.3	-0.4	0.4	-0.4	0.4	0.1
NO_3^-	-0.6	-0.6	-0.6	-0.6	-0.6	0.4	0.2		-0.6	-0.1	-0.4	-0.1	0.7	0.2
Cl^-	0.9	0.1	0.2	0.2	0.2	-0.8	-0.3	-0.6		-0.6	0.5	0.0	-0.5	-0.2
PO_4^{-3}	-0.5	0.3	0.1	0.1	0.1	0.3	-0.4	-0.1	-0.6		-0.6	0.3	-0.1	-0.1
SO_4^{-2}	0.5	0.6	0.7	0.7	0.7	-0.1	0.4	-0.4	0.5	-0.6		0.2	-0.2	-0.1
NH_4^+	-0.1	0.7	0.7	0.7	0.7	-0.1	-0.4	-0.1	0.0	0.3	0.2		0.1	-0.6
TC	-0.8	-0.2	-0.3	-0.3	-0.3	0.1	0.4	0.7	-0.5	-0.1	-0.2	0.1		-0.4
FC	0.2	-0.4	-0.4	-0.4	-0.4	0.6	0.1	0.2	-0.2	-0.1	-0.1	-0.6	-0.4	

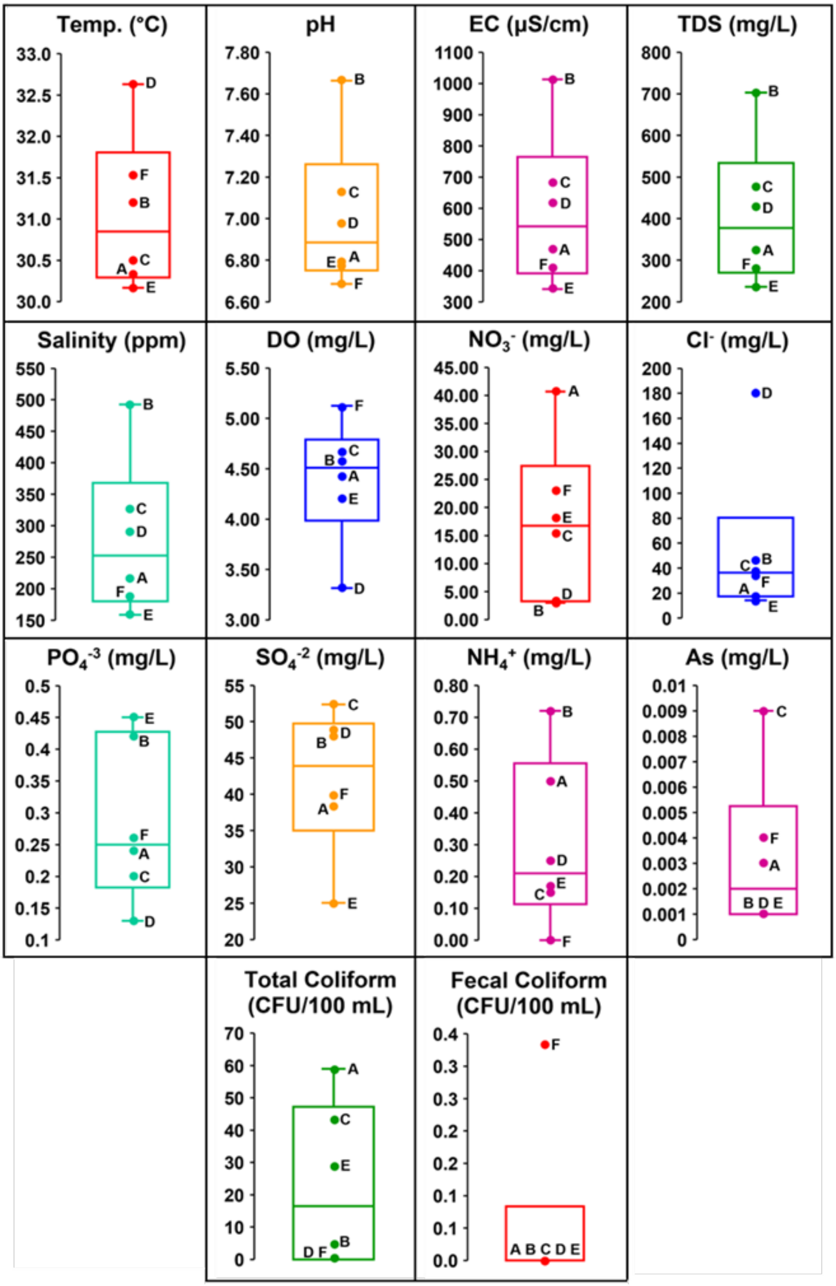
Legend

+	0.7	Very high positive correlation
+	0.5	High positive correlation
+	0.3	Medium positive correlation
+	0.1	Low positive correlation
	0	No correlation
-	0.1	Low negative correlation
-	0.3	Medium negative correlation
-	0.5	High negative correlation
-	0.7	Very high negative correlation

Outliers identified in chloride and fecal coliform plots. Temp.= temperature, EC= electrical conductivity, TDS= total dissolved solids, DO= dissolved oxygen, NO_3^- = nitrate, Cl^- = chloride, PO_4^{-3} = phosphate, SO_4^{-2} = sulfate, NH_4^+ = ammonium, As= arsenic.

Figure 14

Box and whisker charts (1.5 IQR outlier test). Outliers were identified in chloride and fecal coliform plots.



Temp= temperature, EC= electrical conductivity, TDS= total dissolved solids, DO= dissolved oxygen, NO_3^- = nitrate, Cl^- = chloride, PO_4^{-3} = phosphate, SO_4^{-2} = sulfate, NH_4^+ = ammonium, As= arsenic.

Geospatial Distribution of Contaminants

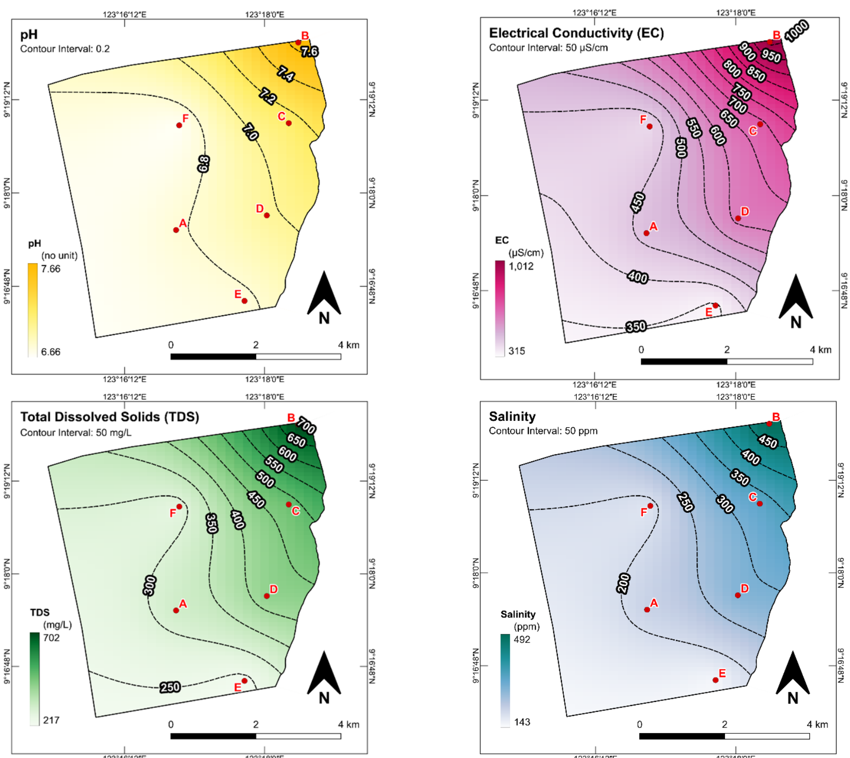
The concentration isopleth maps (Figures 15 to 16) show that pH, EC, TDS, salinity, and sulfate exhibit a northeastward increasing trend toward the coast. This suggests higher alkalinity and dissolved particles (salts, ions, minerals) in that direction. The highest chloride concentration was noted at Site D (Calindagan), an outlier. By excluding this outlier, chloride shows an increasing trend toward the northeast, similar to pH, EC, TDS, salinity, and sulfate (see linear regression plots, Figure 18).

DO levels show a decreasing trend from northwest to southeast where Site D (Calindagan) is located. This may be related to pollution from a long history of industrial land use in the Calindagan area. Nitrate concentrations show an increasing trend towards the west.

Total coliform levels do not appear to show a regional trend. The significant distances (>2 km) between the sampling sites and the likely localized impact from nearby septic tanks and sewer pipes (or sewage ditches) would preclude any regional correlation of the sampling sites.

Figure 15

Concentration Isopleth Maps of pH, EC, TDS, salinity, DO, and Nitrate.



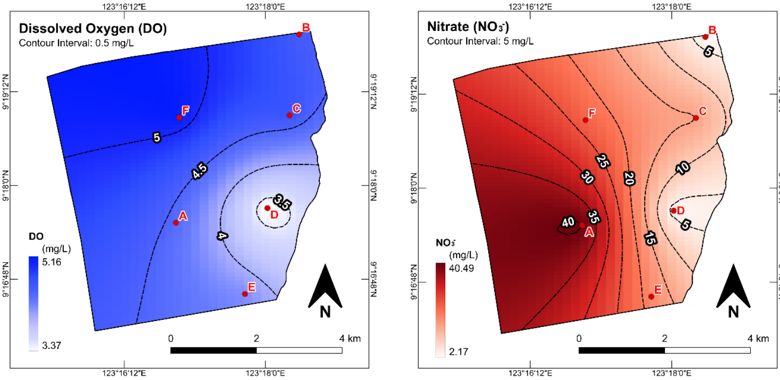
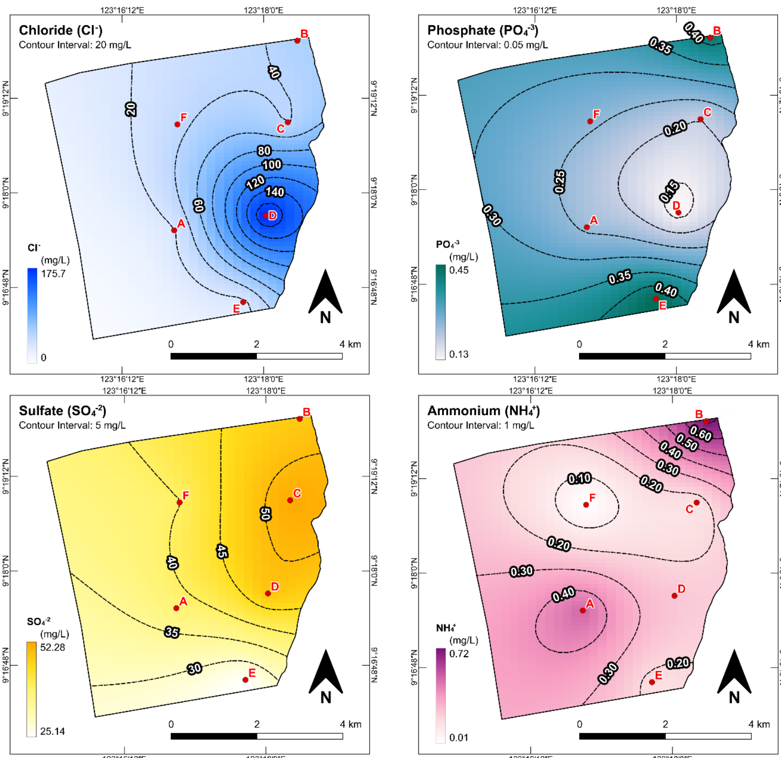
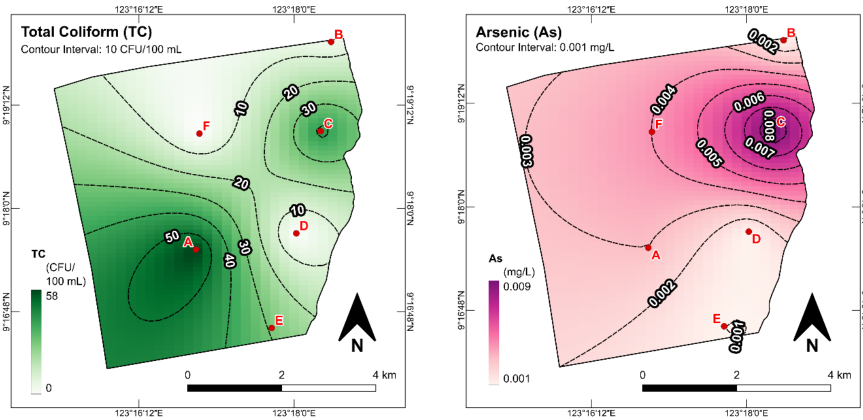


Figure 16

Concentration Isopleth Maps of Chloride, Phosphate, Sulfate, Ammonium, Total Coliform, and Arsenic.





Pollution Index of Groundwater (PIG)

Based on the PIG evaluation, Sites C and D are the least polluted ("insignificant pollution"). (See Table 5.) Sites A, B, and F have "low pollution," while Site E has "moderate pollution" for PIG calculations that exclude coliform. For PIG calculations that include coliform results (total and fecal coliform), groundwater at Sites D and F have insignificant pollution, while Site B has moderate pollution. Sites A, C, and E are classified as having "very high pollution." Calculations were based on Subba Rao (2011), with relative weight assignments (Rw) based on primary and secondary referenced standards and guidelines (see further discussion in section 4.7).

Table 5

Results of Pollution Index of Groundwater (PIG) Evaluation

Sampling Site	PIG Value (Without Coliform)	Classification (Without Coliform)	PIG Value (With Coliform)	Classification (With Coliform)
A (Junob)	1.2	Low Pollution	6.4	Very High Pollution
B (Bantayan)	1.4	Low Pollution	1.5	Moderate Pollution
C (Daro)	0.9	Insignificant Pollution	4.7	Very High Pollution
D (Calindagan)	0.6	Insignificant Pollution	0.5	Insignificant Pollution
E (Banilad)	1.5	Moderate Pollution	3.8	Very High Pollution
F (Batinguel)	1.1	Low Pollution	0.9	Insignificant Pollution

Insignificant pollution (PIG < 1.0), low pollution (1.0 < PIG < 1.5), moderate pollution (1.5 < PIG < 2.0), high pollution (2.0 < PIG < 2.5), and very high pollution (2.5 < PIG).

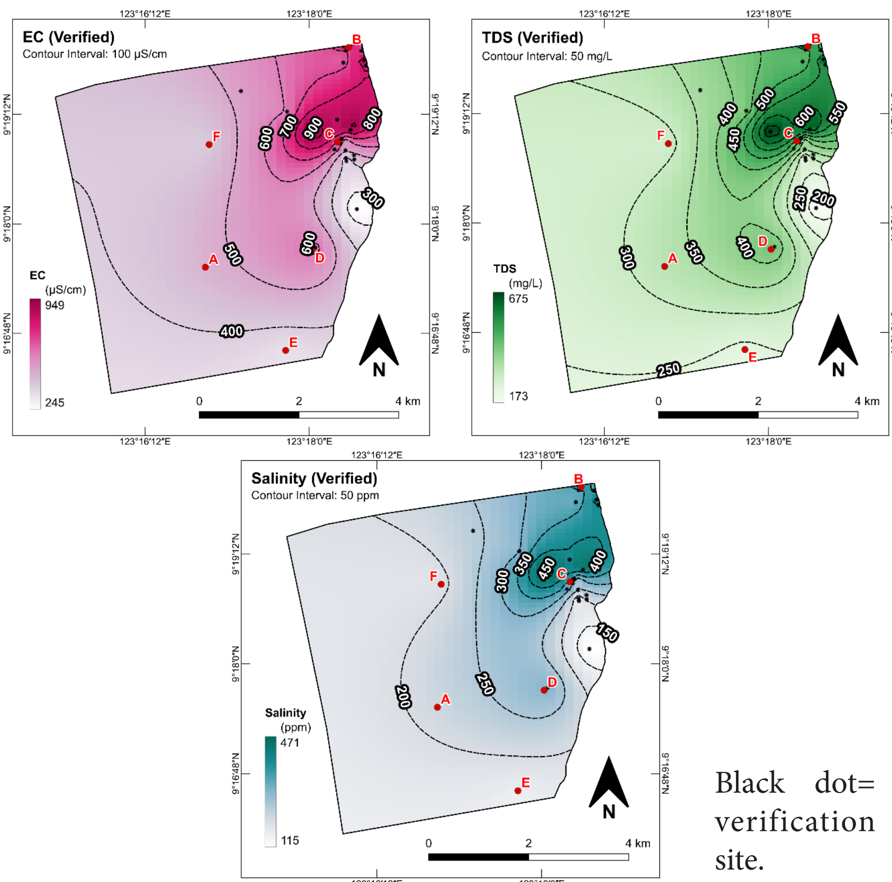
Discussion

Saltwater Intrusion

Spatial distribution (concentration isopleth) maps (see Figures 15-16) showed that the city's northeastern section had relatively higher pH, EC, TDS, and salinity levels. Linear regression of chloride values (excluding the outlier at Site D) also shows this trend (Figure 18). The readings were highest at Site B (Bantayan) and lowest at Sites A (Junob) and E (Banilad). This trend was verified by a subsequent supplemental survey using the EC500. Randomly tested community and domestic wells and natural springs confirmed the higher levels of EC, TDS, and salinity in the northeast section of the city (Figure 17). These results suggest some localized influence from saltwater (saltwater lens or intrusion?) in the city's northeast section.

Figure 17

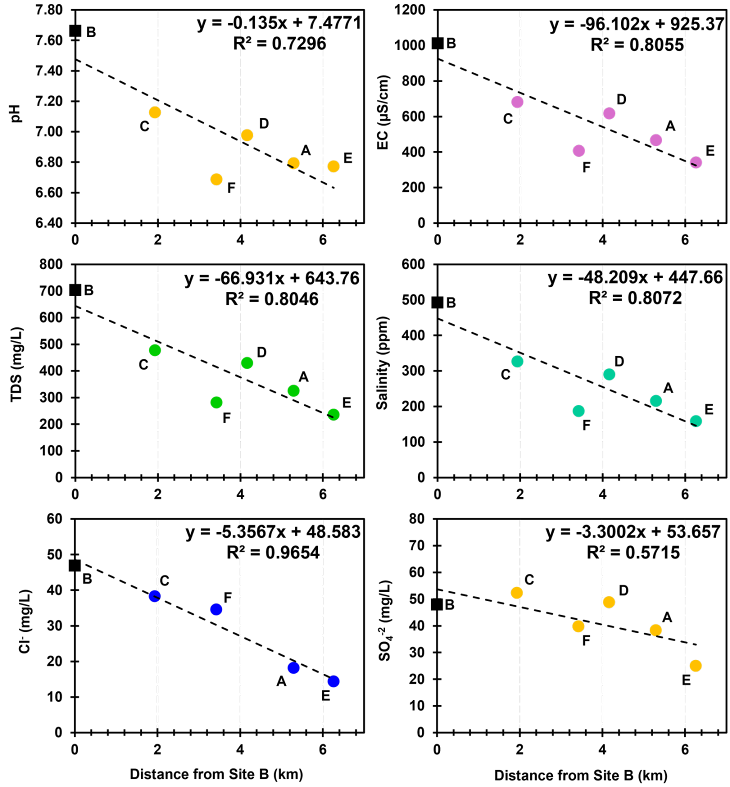
Concentration Isopleth Maps of EC, TDS, and Salinity with Verification



Black dot= verification site.

Figure 18

Linear Regression Scatter Plot of Concentration vs. Distance from the Northeast



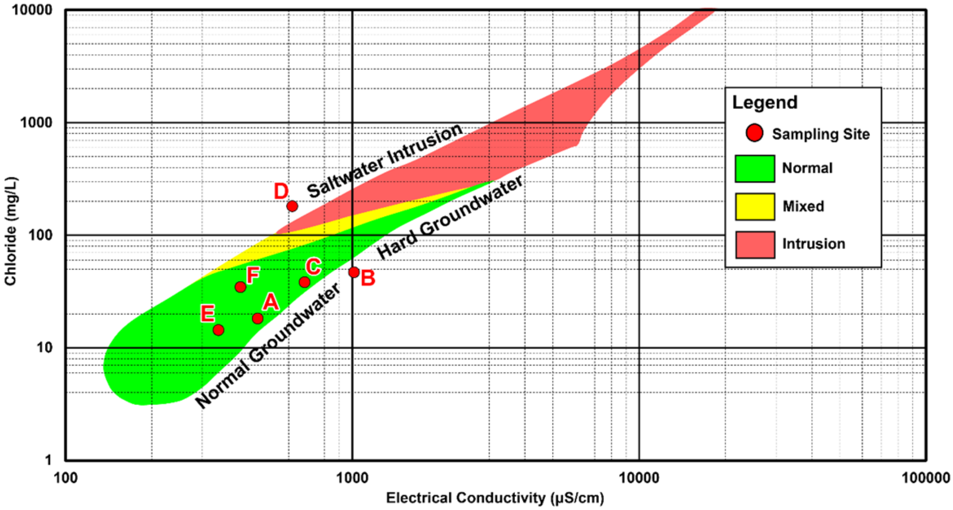
Note: Site B is the reference point, as indicated by a black square. Site D (outlier) is excluded from the linear regression analysis for chloride. EC= electrical conductivity, TDS= total dissolved solids, Cl- = chloride, SO_4^{-2} = sulfate.

Based on a study of saltwater intrusion in British Columbia, Canada, Klassen et al. (2014) concluded that groundwater there was influenced by saltwater intrusion as characterized by chloride (Cl^-) concentrations exceeding 200 mg/L and EC levels exceeding 1,000 µS/cm. Chloride concentrations between 100-200 mg/L and EC between 600-2,000 µS/cm indicate a mixing of freshwater and saltwater. This is shown on a Cl^- versus EC log-log plot based on a study (Kelly 2005) of saltwater intrusion in Washington State, U.S.

Using this classification and upon plotting on the Kelly (2005) log-log plot, most of the sites in this study fall within the normal or freshwater zone (Figure 19). However, sites D (Calindagan) and B (Bantayan) appear to fall into transition zones. Site D with chloride at 181 mg/L and EC at 617 µS/cm plots slightly outside the zones but in the general area of the mixed (fresh and saltwater) zone. This contrasts with the fresher groundwater south of the Banica River, which has EC levels < 300 uS/cm (Caranto, 2005). Site B plots outside the normal and "hard groundwater" zones but has an elevated EC value (1,013 µS/cm) that correlates to elevated TDS and salinity, which distinguishes it from "normal" groundwater.

Figure 19

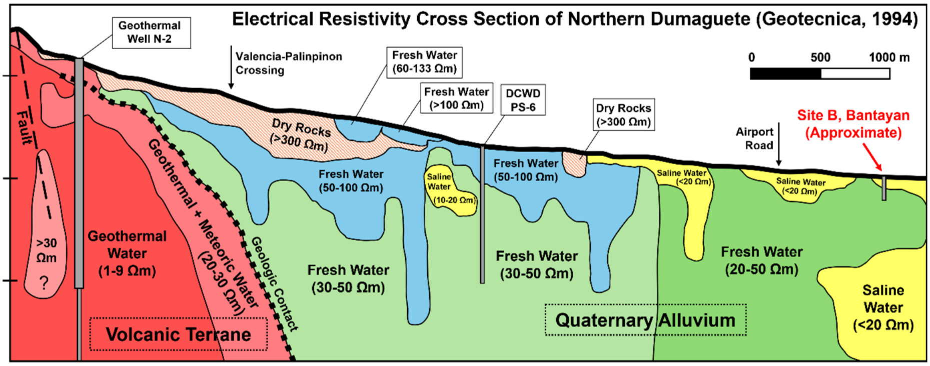
Chloride (Cl-) vs. Electrical Conductivity (EC) Scatter Plot, with Zones Classified as Normal Groundwater, Hard Groundwater, Saltwater Intrusion, and Mixed Groundwater (modified from Kelly, 2005).



It is postulated that the deep well (~80 ft) at Site B (Bantayan), and possibly other deep wells in the northeast section of the city, are pumping groundwater from a point that is close to the zone of dispersion or mixing zone where the deep saltwater below the coastline mixes with the shallower freshwater from inland. Alternatively, the well at Site B may be withdrawing water from a point near an adjacent lens or pocket of saline water in the subsurface (also described as a "fossil" or a "wedge" of saline water by Geotecnica, 1994). Most other shallower wells (e.g., 20 ft deep domestic wells) are likely pumping from the shallow freshwater lens above the mixing zone or lens of saline water. Figure 20 is an east-west cross-section of the georesistivity survey in the city's northern section (from Geotecnica, 1994), showing wedges or pockets of saline (low resistivity) groundwater.

Figure 20

The Electrical Resistivity Cross-section of Northern Dumaguete City (modified after Geotecnica, 1994)



The electrical resistivity survey generated by this cross-section was conducted along Rovira Drive from Barangay Bantayan to Barangay Ticala (in Valencia). Higher resistivity indicates fresher water, while lower resistivity (higher conductivity) indicates more saline water in the Dumaguete aquifer, mamsl= meters above mean sea level.

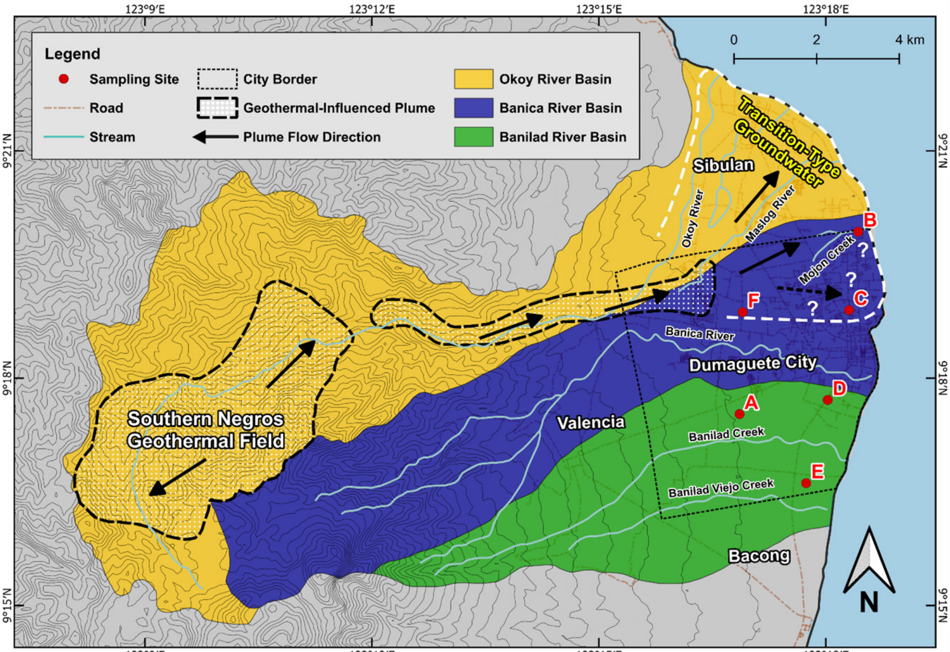
At Site B, the proximity to a subsurface saltwater body or interface is suggested by the relatively high groundwater pH, which is similar to the pH range (7.5 to 8.4) of seawater measured at Silliman Beach in Bantayan (Alcala et al., 2024). M. Alcala (personal communication, 3/20/24) also reported high TDS in the past decades in water from their community supply well, presumed to be about 80-100 feet deep, in the Silliman Park (Bantayan) residential community. (The well was located approximately 350 m south of Site B and decommissioned circa 2013.) However, since the low chloride concentrations at the two northeastern wells (Sites B and C) deviated from the characteristics of saltwater intrusion or mixing, additional investigation is necessary to prove proximity to the freshwater-saltwater interface or the possible onset of saltwater intrusion in the northeast margin of the aquifer. The chloride outlier (181 mg/L) at Site D in Calindagan suggests a similar situation to Site B—proximity to a saline water lens or the freshwater-saltwater mixing zone.

Hot Spring Waters

An alternative explanation for the relatively elevated EC, TDS, and salinity toward the northeast part of the city is the influence of hot spring (geothermal) waters. Caranto (2005) characterized the groundwater in the northern part of the city (and into Sibulan) as a mix of hot spring and meteoric waters (designated as "Ca+Mg-Cl+SO_4 water"). Smaller plumes influenced by hot spring waters ("Na+K-Cl+SO_4 water") were identified in the northwest section of the city and further west in Valencia (Figure 3). A later study by Caranto et al. (2006) reported elevated Na, Li, B, Cl, and SO4 levels at DCWD production (public supply) wells 49, 53, 54, and 55 in the city's northwest section. This indicates an east-trending migration of a groundwater plume rich in geothermal-related ions towards the Dumaguete aquifer. Such ions may have contributed to the study area's relatively high EC, TDS, and salinity.

Figure 21

Migration of Geothermal-influenced Groundwater Plume from the SNGF to the Northeast, (modified after Caranto et al., 2006)



The White dashed line outlines the estimated extent of transition-type groundwater, hypothesized to extend toward Sites B in Bantayan and C in Daro. Other data sources: SWECO/LWUA (2001), NAMRIA, and PhilGIS. Topographic contour interval 20 m.

The relatively high sulfate (SO4-2) levels in the city's northeast section further support this alternative theory (see Figure 16). Sulfate may be associated with geothermal waters. It is a component of the Na+K-Cl+SO4 waters of hot spring origin (Caranto, 2005) and is highly correlated with pH, EC, TDS, and salinity in the Pearson product-moment correlation matrix (Figure 13). The SNGF waters were noted by Rae et al. (2011) to exhibit neutral to slightly alkaline characteristics, which could also explain the the mixed geothermal-meteoric waters and the postulated saltwater dispersion zone, which could explain the relatively high EC, TDS, and salinity readings at Site B (Bantayan).

Geotecnica (1994) indicated in their geochemical study of the SNGF that there was concern that brine-water plumes from the higher elevations of the SNGF may be migrating toward the groundwater aquifer in the alluvial plain to the east, notably in the Bantayan area. The Geotecnica report also concluded that geothermal springs, such as surface- and ground-water arsenic, may contribute to contamination. This was their postulation for detecting arsenic in groundwater samples from a few wells in Dumaguete and several others in Valencia and Sibulan within the Okoy River basin. (Geotecnica's sampling area was concentrated in the western section of Dumaguete City and farther west in Valencia.)

This study detected arsenic at Sites C (Daro) and F (Batinguel). Assuming provenance from geothermal waters, this would extend the plume of geothermal fluid shown on the map of Caranto et al. (2006), which runs from the geothermal field in Valencia toward the east, between Okoy and Banica rivers (Figure 21). Further groundwater investigation (e.g., sampling additional wells at a higher frequency to account for seasonal fluctuation) is needed to confirm the extended plume of such geothermal-influenced waters.

A compilation of historical groundwater sampling results (the 1980s to early 1990s) by Geotecnica (1994) shows varying levels of less than 0.05 mg/L (the previous regulatory limit) of arsenic in artesian wells in the lowland areas adjacent to the SNGF (i.e., including the Dumaguete aquifer). Compared to the current arsenic drinking water standard of 0.01 mg/L, many historical sampling results exceeded the current standard. Thus, arsenic in groundwater remains a contaminant of concern.

Natural Minerals in Soil

The WHO (2011, 2022) reported that naturally occurring minerals primarily contribute to elevated sulfate concentrations in groundwater worldwide. The soils underlying Dumaguete are derived from weathering and erosion of volcanic rocks, which are known to be rich in sulfide minerals like pyrite (FeS2). The breakdown of sulfide minerals by water and oxygen generates sulfate compounds and ions in sediments and soils. Such a process offers an alternative origin of sulfate contamination in the groundwater in the study area. However, compared to the referenced drinking water standards, the sulfate concentrations in the study area, ranging from 25.06 to 52.37 mg/L, were below the threshold of 250 mg/L and are not a significant health concern.

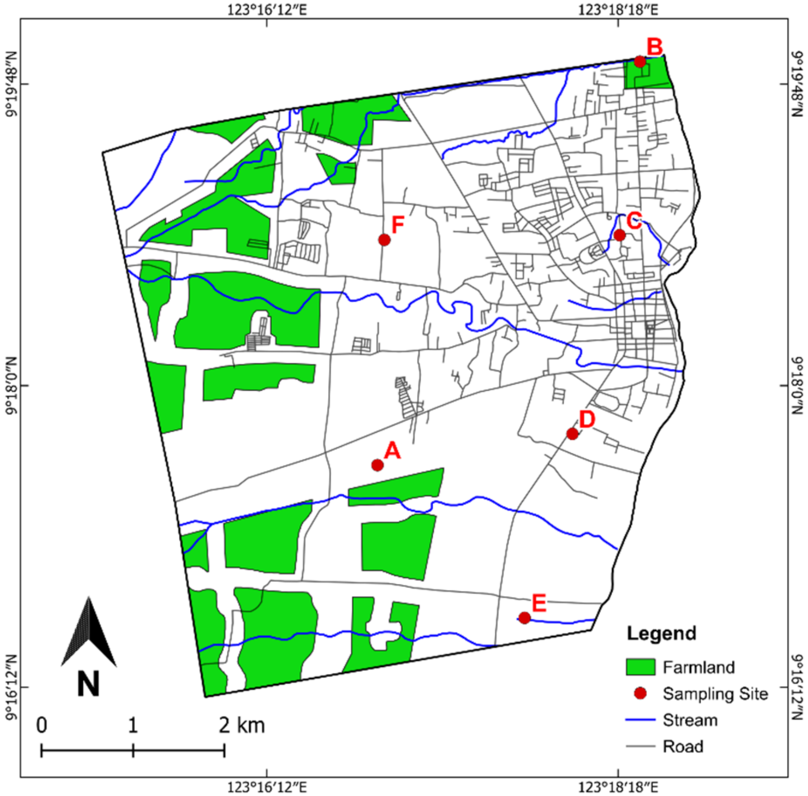
Sulfide mineral and volcanic deposits may also significantly contribute to elevated arsenic concentrations in groundwater (WHO, 2011, 2022). Arsenic is a component of several minerals, most commonly in arsenopyrite (FeAsS). In this study, Sites C and F (barangays Daro and Batinguel) exhibited relatively higher arsenic concentrations (0.009 and 0.004 mg/L, respectively), which can be attributed to subsurface volcanics or volcaniclastics. However, further study is warranted to investigate such a notion.

Agricultural Activity

Agricultural land use is one of the likely sources of contaminants in barangays Junob and Bantayan. Four of the six samples in this study had nitrate levels exceeding referenced standards. The proximity of Site A (Junob) to active agricultural fields in the area, coupled with the long history of agricultural use, can explain the elevated nitrate concentration in the groundwater sample from Site A. Furthermore, the geospatial distribution trend of increasing nitrate concentrations westwards (see Figures 15 and 22) correlates with the increasing agricultural land usage toward the west. The WHO (2011, 2022) identifies the application of inorganic nitrogenous fertilizers and manure in agriculture as the primary cause of nitrate contamination in groundwater. Similarly, the sample from Site B (Bantayan), although having lower nitrates, had higher ammonium (NH4+) and phosphate (PO4-3) levels, which reflect the long history of agricultural use of this area (as Silliman Farm).

Figure 22

Map of Agricultural Land Use in Dumaguete City (2013-2023), (modified after Emmanuel, 2017)



Urban Activity

The phosphate levels at all six sampling sites exceeded the referenced limits. Nitrate levels at four sites also exceeded the referenced limits. While the highest nitrate concentration was found at Site A (Junob), associated with active agricultural use, other sources from urban activities may account for the nitrate levels at the other sites. Wastewater disposal, including that associated with leaky septic tanks and sewer pipes, introduces nitrates from human and animal waste (WHO, 2011, 2022). Additionally, various industrial processes contribute to nitrate levels, including processing meat and crops and producing dairy (DENR, 2016).

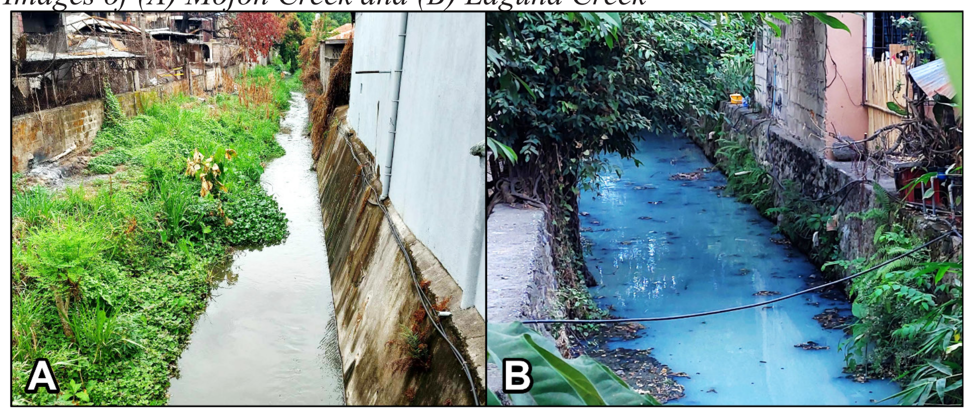
Phosphates are found at higher concentrations in residential areas and locations with dense populations due to activities like sewage discharge and household laundry and cleaning practices (DENR, 2016). Thus, the phosphate and nitrate results for the study area reflect agricultural uses of the land (e.g., at sites A, B, and D) and urban activities associated with increasing population.

Likewise, ammonium at Site B (Bantayan) may be associated with urban activity, mainly via infiltration from the polluted Mojon Creek. The recent study by Alcala et al. (2024) found relatively high levels of ammonia and other contaminants in the surface water samples collected from the mouth of Mojon Creek. The creek runs through densely populated sections with several industrial and commercial facilities. It exhibits intermittent high turbidity, dark coloration, and sewage odor indicative of contaminants, most likely including ammonia and ammonium. As a losing stream along much of its mainstem, the creek is likely contributing to groundwater contamination at Site B and other areas in Bantayan.

Site C in Daro is situated near Laguna Creek, a heavily polluted drainage ditch (Figure 23) and a likely source of contamination where it loses water as a losing stream into the aquifer. The high total coliform reading at Site C most likely originated from the highly polluted creek, which is only 90 m from the sampled well.

Figure 23

Images of (A) Mojon Creek and (B) Laguna Creek



Similarly, the total coliform results were high at Site E (natural spring), where the residential community has many septic tanks buried in highly permeable sandy soil and many sewage ditches. Animal waste from domestically-raised poultry and free-ranging cows was also ubiquitous in this community. Furthermore, this area in Banilad is characterized by a water table encountered at 1-2 m (and shallower) below grade. Such a combination of multiple land use, waste disposal, permeable soils, and shallow groundwater provide conditions conducive to a dispersion of bacteria and other contaminants into the aquifer.

The well at Site A (Junob) had the highest bacteria levels among all sampling sites. Since the area is now a construction site with no visible signs of bacterial sources, the origin of bacteriological contamination was perplexing. However, since it was known that the well was last used as a domestic well for a former residence, it is likely that an old, leaking septic tank may have existed nearby.

The very high correlation of total coliform with nitrate in the Pearson product-moment correlation matrix for this study further supports the notion that leaky septic tanks, sewage discharge (via leaky pipes and ditches), and other surface waste discharges are the likely sources of total coliform.

Site D in Calindagan presented a unique case. Relatively high temperatures suggest that surface water infiltration is attributed to warm, ponded sewage water near the well. Such a pond is heated by the sun daily and likely seeps rapidly into the groundwater, particularly along the well's steel casing. High chloride at Site D suggests the possibility of proximity to a saltwater lens or a zone of freshwater-saltwater mixing. Alternatively, the high chloride and low dissolved oxygen (DO) may indicate contamination from the sewage puddle and old septic tanks (the closest one being less than 10 m away). Other potential sources include an adjacent auto repair shop and commercial-industrial facilities within a hundred meters from this well. Although testing for this study revealed no current coliform issues, intermittent bacterial contamination is suspected. The high chloride content during sampling may be responsible for inhibiting bacterial growth. The owner reported that a previous lab analysis resulted in a high bacterial count. Such testing was initiated after her experience with bacterial infection, attributed to drinking water from the well.

A similar condition was observed at Site F in Batinguel, where a bacteriological sample yielded one colony-forming unit (CFU) of fecal coliform during one of the three trials. Such positive coliform result and the second highest nitrate levels among the six sites can be linked to the nearby (<7 m away) septic tank and sewage puddle very near the well at Site F.

Impact from Dumpsite

Of the six sampling sites, only Site F (Batinguel) would likely be impacted by leachate from the Dumaguete dumpsite located in barangay Candau-ay, 2.3 km west of Site F. Such location puts Site F in a hydraulically downgradient location from the dumpsite. The parameters for this study included the heavy metals arsenic, cadmium (Cd), lead (Pb), and mercury

(Hg), and ions (nitrate, chloride, phosphate, sulfate, and ammonium). Other physico-chemical parameters included pH, EC, TDS, salinity, and DO. Bacteriological (coliform) analysis was also added to the analyses. While most of these parameters can be attributable to the dump site, the analytical results and statistical evaluation did not indicate a significant trend or outliers. However, based on the results of the recent study by Romo (2024), which involved sampling six wells between the dumpsite and Site F of this study (a distance of 2.3 km), elevated levels of ammonium and phosphate were detected; such contamination was confirmed by low DO and high BOD levels. This suggests that a leachate plume has developed underneath the dumpsite and is likely migrating eastward. It is suggested that elemental and isotopic chemical investigations be conducted to confirm the provenance of contaminants from the dump site.

Overall Water Quality Assessment

The results of this study raise concerns for all stakeholders relying on groundwater as a potable water supply. Elevated levels of TDS at Site B exceeded safe drinking water standards, while sites C and D had high TDS levels that approached the 500 mg/L USEPA guideline. Five sites failed the minimum DO threshold of 5 mg/L. All six sites exceeded the DENR's phosphate threshold of 0.025 mg/L. Four sites exceeded the nitrate thresholds of 7 and 10 mg/L of the DENR and USEPA, respectively. Four sites exceeded the total coliform limit of 1 CFU/100 ml of the DOH. Arsenic levels were all below compliance levels, but one well (Site C) had arsenic at 0.009 mg/L, at the borderline of the drinking water standard of 0.01 mg/L.

Low DO levels typically indicate high contamination. Such low levels at most sites suggest the presence of additional contaminants, i.e., parameters not analyzed for in this study, such as volatile organics, oil-and-grease, polynuclear aromatic hydrocarbons (PAHs), and other organic compounds. The elevated phosphate at all sites makes the pumped water prone to algal growth. Nitrate concentrations in Junob, Daro, Banilad, and Batinguel exceeded the recommended limits of the DENR and the USEPA. Nitrate exceeding 10 mg/L in drinking water is a high risk for infants, i.e., prone to blue baby syndrome (MDH, 2023). High coliform in Junob, Daro, Banilad, and some total coliform in Bantayan, along with trace fecal coliform in Batinguel, is a cause for concern for well owners. Coliform in drinking water is associated with disease-causing microorganisms to which infants, children, elderly people, and people with weakened immune systems are most vulnerable (MDH, 2023).

The PIG statistical evaluation depended on a subjective weight assignment to the parameters. For this study, parameters with primary or mandatory drinking water standards were given a weight of 5, like TDS and metals; those with secondary standards were assigned a value of 4, while those with no standards were assigned a value of 3. The PIG results for geochemical parameters (coliform excluded) indicated that only one site (Site E, Banilad) was concluded to be moderately polluted, while the rest were of low to insignificant pollution. Site E (with a PIG value of 1.5, moderate pollution) was based on nitrate and phosphate exceeding the referenced standards, accompanied by other parameters that influenced the calculations. The other three "low pollution" (PIG values of 1.1, 1.2, and 1.4) sites had at least one parameter exceeding its referenced standard and other low-significance parameters. In contrast, the two "insignificant pollution" sites (with PIG values less than 1.0) had no exceedance.

Following the addition of bacteria levels in the recalculation, four sites were considered "moderate" (PIG value 1.5) and "very high" (PIG values 3.8, 4.7, and 6.4) in pollution indices. These results are influenced by bacterial contamination. This PIG method of evaluation would appropriately apply to a large and highly polluted region where regulatory "compliance averaging" is acceptable and does not require each hotspot or area of concern to be separately addressed or remediated.

Conclusions

Higher levels of pH, EC, TDS, salinity, and sulfate occur in the northeast section of the city. Notably, TDS in Bantayan exceeded drinking water standards. This phenomenon may be attributable to the transition-type (i.e., variably mixed geothermal and meteoric) groundwater influenced by geothermal waters in the upland areas, as characterized by Caranto et al. (2006), or proximity to a freshwater-saltwater mixing zone as indicated by the higher pH and chloride levels, and proximity to the coast. In Calindagan, the anomalous chloride level and elevated EC, TDS, and salinity may also be attributable to proximity to a freshwater-saltwater mixing zone; however, an alternative origin of chloride might be from urban pollution, particularly the local ponded sewage water and possibly old, leaky septic tanks in this historically commercial-industrial area.

Arsenic was detected in Batinguel and Daro, with the highest level in Daro (0.009 mg/L). Such concentration borders the regulatory limit (0.01 mg/L). The source of arsenic, along with higher sulfate levels, could be from upland geothermal waters such as hot springs. An alternative provenance might be from the underlying volcanic and volcaniclastic rocks.

All phosphate results exceeded DENR guidelines for Class A water bodies, while nitrate exceeded referenced limits at four sites. All ammonium results were well below the referenced limits. Nitrate, phosphate, and ammonium varied from site to site, but a common contaminant source might be the historical agricultural land use combined with the rapid urbanization of the city, polluted ditches and creeks, and discharges from old, leaky septic and sewer systems. Increasing nitrate levels toward the west reflect the increasing agricultural use westward.

Coliform levels were significant in agricultural and residential areas (Junob, Daro, and Banilad), with trace presence at sites B and F (Bantayan and Batinguel, respectively). Such occurrence can be associated with nitrate sources, specifically historical agricultural use (e.g., fertilizers, animal waste discharge), leaking septic and sewer systems, and polluted puddles, ditches, and creeks.

The PIG evaluation indicated moderate to very high pollution indices in Junob, Daro, Banilad, and Bantayan. While overall pollution indices from the PIG evaluation were insignificant in Calindagan and Batinguel, localized sources of contamination were noted, such as old septic tanks and lingering sewage puddles near the wells. Applying PIG evaluation would be more useful in a highly contaminated and large region with numerous sampling points, where compliance is mandatory, and averaging is acceptable.

Recommendations

- Implement a water quality monitoring program using a network of selected public wells and shallow community and domestic wells; periodic sampling of such wells. Initial sampling parameters, particularly those wells closest to the former dumpsite, should include volatile organics, priority pollutant metals, PCBs, and pesticides. These are in addition to the parameters addressed in this study and are required by the DENR as mandatory or primary parameters. Subsequent monitoring will depend on contaminants identified in initial testing.
- Conduct a geochemical study to determine provenance: saltwater, geothermal, or mixed groundwater origin in the city's northern half. This may involve elemental geochemistry and comparison with the characteristics of hot spring waters in the geothermal field and saltwater from the sea. An isotope study would complement elemental geochemistry.

- Drill and install soil borings , piezometers, and monitoring wells to establish the hydrogeology of the auifer. Information should be collected from existing public and private deep wells to collect more data such as water levels, well screen depths, and well construction information. The monitoring wells can be used for groundwater quality monitoring.
- Identify the tributaries and delineate the drainage basins of the Banilad, Mojon, and Maslog creeks; determine the points along each stream (including the Okoy and Banica Rivers) where it becomes a gaining or losing stream. This would provide information to refine the aquifer model and assist in predicting contaminant movement to or from a stream.
- Collate all well information (e.g., drilling logs, pumping rates, pumping tests, water levels, etc.) for updated groundwater modeling and simulation using software like MODFLOW. Such modeling and simulation would provide updated water budgets, transient drawdowns, and long-term (steady-state) drawdowns.
- Identify areas with shallow wells at risk of pumping dry. Good management of well spacing, pumping rates, drawdowns, and basin-wide water levels would determine the long-term sustainability of the groundwater aquifer.

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