



Groundwater Quality Dynamics in the Coastal Aquifer of Tipo-Tipo, Basilan, Philippines

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ABSTRACT:

In coastal areas like Tipo-Tipo, Basilan, groundwater isn't just a resource; it's a daily necessity. Families rely on it for drinking, farming, cooking, and cleaning. But this lifeline is quietly being threatened by saltwater intrusion. The study aims to assess the hydrochemical characteristics of groundwater in the coastal aquifer of Tipo-Tipo, Basilan, by measuring key physico-chemical parameters such as pH, electrical conductivity, salinity, total dissolved solids, and major ions, determine the possible saltwater intrusion and its impact on groundwater quality, and compare the quality based on the WHO and PNSDW standards. The groundwater samples were collected from existing wells during both high and low tides and tested for key indicators, including EC, pH, TDS, Temperature, Cl, SO₄, TA, Ca, Mg, Na, K, CO₃, and HCO₃. The findings revealed clear changes in water quality between high and low tide. During low tide, the concentration of salt and minerals, such as chloride, sodium, and magnesium, increased noticeably, indicating that seawater was intruding into the freshwater supply. The shift in water composition, from magnesium-sulfate to magnesium-chloride, confirmed that saltwater was intruding into the inland; however, all results were within safe limits, based on WHO and PNSDW. This study provides relevant information that the coastal groundwater of Tipo-Tipo needs to be protected and managed more carefully.

1. Introduction

In many coastal and island communities, groundwater is more than just a resource; it is a lifeline. For places like the Philippines, where thousands of islands comprise the national landscape, groundwater is the primary source of freshwater for drinking, farming, and daily household use. Nearly half of the country's water supply and most rural areas rely heavily on this hidden reservoir beneath the earth's surface [1-2]. Yet, this crucial resource is increasingly under threat.

Coastal aquifers, in particular, face a complex web of challenges. Being near the sea makes them vulnerable to saltwater intrusion, especially when water is drawn out faster than nature can replenish it. Add to that the effects of pollution from farming, inadequate sanitation systems, and the growing impacts of climate change, such as rising seas, erratic rainfall, and warming temperatures, and the risk becomes even greater [3-4]. These

challenges are not unique to the Philippines but are shared by many coastal communities worldwide that often lack the tools and data to monitor and protect their groundwater [5-6]. The municipality of Tipo-Tipo in Basilan is one such place. Like many rural areas, it depends almost entirely on shallow wells for water. However, there have been no detailed scientific studies to understand how safe or sustainable this water is. Local observations suggest seasonal changes in taste and salinity, but without proper monitoring, it's difficult to know what's happening beneath the surface. Compounding this is the area's porous limestone geology, which allows contaminants to seep through easily, and land use practices that may be unintentionally harming water quality [7].

Objectives

1. Assess the hydrochemical characteristics of groundwater in the coastal aquifer of Tipo-Tipo,



Basilan, by measuring key physico-chemical parameters such as pH, electrical conductivity, salinity, total dissolved solids, and major ions.

2. Determine the possible saltwater intrusion and its impact on groundwater quality
3. Determine the groundwater quality based on the WHO and PNSDW standards.

Methods

The Study Area

This study was conducted in Tipo-Tipo (Fig. 1), a coastal municipality in the eastern part of Basilan Province, under the Bangsamoro Autonomous Region in Muslim Mindanao (BARMM), Philippines. As of the 2020 national census, Tipo-Tipo has a population of approximately 30,000 residents, the majority of whom rely on subsistence agriculture, fishing, and small-scale trade for their livelihood (Philippine Statistics Authority [8]. With limited access to piped water infrastructure, most households rely on shallow groundwater sources such as open-dug wells, hand pumps, and spring catchments for drinking, sanitation, and irrigation.

Geographically, Tipo-Tipo is bounded by Lamitan City to the north, Ungkaya Pukan to the west, and Al-Baraka to the south, with the Sulu Sea forming its eastern coastal boundary. This proximity to the sea offers both ecological richness and hydrological risk, particularly the potential for saltwater intrusion into coastal aquifers due to over-extraction or sea-level rise [9-10]. The area is underlain by porous limestone and volcanic formations, along with alluvial deposits, which allow easy infiltration of rainwater but also make the aquifer highly susceptible to contamination from surface activities [11].

Tipo-Tipo falls under the tropical rainforest climate (Af) classification, with mean annual temperatures ranging from 26°C to 28°C and rainfall exceeding 2,500 mm annually [12]. Most of this precipitation is concentrated during the southwest monsoon season from June to November, contributing to groundwater recharge. However, high rainfall also increases the risk of surface runoff, erosion, and infiltration of pollutants, especially in areas with poor waste disposal or intensive land use [1, 5].

Sampling and Analysis

The groundwater samples were collected once during high and low tides from existing groundwater wells on the coast of Tipo-Tipo. About two (2) minutes of purging were done before the sample collection. Before collecting the groundwater, the sampling bottles were thoroughly cleaned using a detergent. A total of 1.5 L of water samples were collected from each well. Following the standard procedures set by the Philippine National Standard for Drinking Water [10], filled bottles were tightly capped and properly labeled with the following information: 1) the date and time of sampling, and 2) the sample source. Sampling bottles were placed in an icebox at a low temperature to prevent unnecessary chemical reactions. The water samples were transported to a laboratory for analysis. Unstable parameters such as pH, total dissolved solids (TDS), temperature, and electrical conductivity (EC) were measured directly in the field using a portable multimeter. At the same time, other analyzed physicochemical parameters are outlined in Table 1.

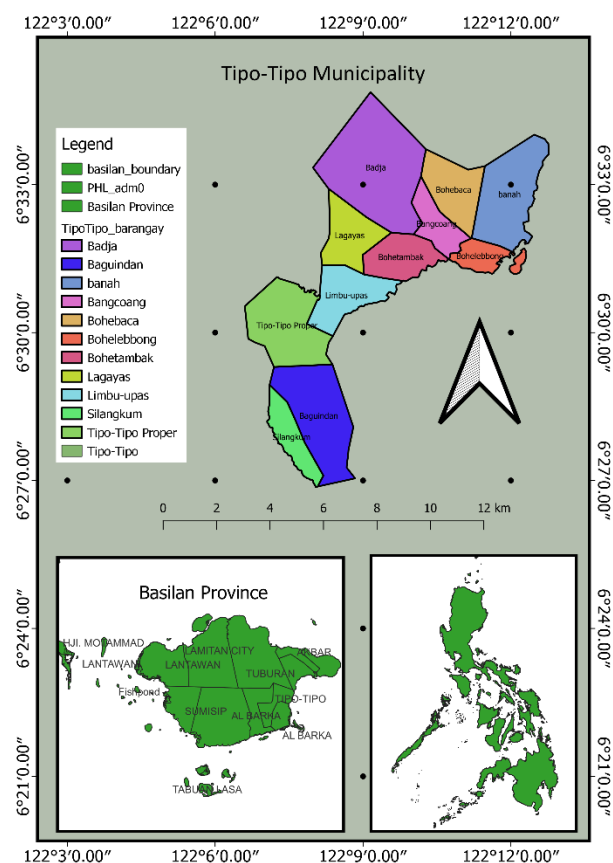


Figure 1. Map of the Study Area



Table 1. Method of Testing the Groundwater Physico-Chemical Parameters

Parameters	Test Method
Chloride	4500-Cl-B. Argentometry
Sulfate	4500-SO42-E. Turbidity
Total Alkalinity	2310 B Titrimetry
Calcium	3030 F. Nitric Acid-Hydrochloric Acid Digestion, 3111 B. Acetylene Flame AAS
Magnesium	
Sodium	3030 F. Nitric Acid-Hydrochloric Acid Digestion, 3111 B. Direct Air-Acetylene Flame AES
Potassium	
Carbonate	Computation
Bicarbonate	
Total Dissolved Solids	Hand-held EC-meter (onsite)
pH	Hand-held EC-meter (onsite)
Electrical Conductivity	Hand-held EC-meter (onsite)
Temperature	Hand-held EC-meter (onsite)

Computation of Carbonate and Bicarbonate

Bicarbonate will be computed through the use of the equation [13]. $\text{HCO}_3^- = 10^{(\text{pH}-5.05)}$, while carbonate will be computed using this equation, Total Alkalinity = $[\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [\text{OH}^-] - [\text{H}^+]$.

2. Results

Table 2. Concentration of Tested Groundwater Parameters, March 2022

Parameters	Tides	
	HT (mg/L)	LT (mg/L)
EC	250.88	289.28
pH	8.13	7.9

TDS	197	218
Temp.	29.9	28.6
Cl	2.2	21.2
SO4	10	10
TA	23.1	184
Ca	1.1	7.41
Mg	2.6	22.1
Na	2.7	25.3
K	0.1	2.59
CO ₃	8.13E-06	2.82E-06
HCO ₃ ⁻	1.2	0.71

Table 3. Concentration of Tested Groundwater Parameters (mg/L) During High Tide Compared with the WHO and PNSDW

Parameters	High Tide	WHO	PNSDW
EC	250.88	-	-
pH	8.13	6.5 - 8.5	6.5 - 8.5
TDS	197	500	600
Temp.	29.9	-	-
Cl	2.2	250	250
SO ₄ ²⁻	10	250	250
TA	23.1	200	-
Ca	1.1	75	-
Mg	2.6	50	-
Na	2.7	200	200
K	0.1	12	-
CO ₃ ²⁻	8.13E-06	-	-
HCO ₃ ⁻	1.2	-	-



Table 3. Concentration of Tested Groundwater Parameters (mg/L) During Low Tide Compared with the WHO and PNSDW

Parameters	Low Tide	WHO	PNSDW
EC	289.28	-	-
pH	7.9	6.5 - 8.5	6.5 - 8.5
TDS	218	500	600
Temp.	28.6	-	-
Cl	21.2	250	250
SO ₄	10	250	250
TA	184	200	-
Ca	7.41	75	-
Mg	22.1	50	-
Na	25.3	200	200
K	2.59	12	-
CO ₃	2.82E-06	-	-
HCO ₃ ⁻	0.71		

Table 4. Phases and Facies of Groundwater of Coastal Aquifer During High and Low Tides in the Sampling Well of Tipo-Tipo Municipality

HIGH TIDE			LOW TIDE		
Phase	Facies		Phase	Facies	
Freshening	Mg	SO ₄	Intrusion	Mg	Cl

Discussion

Measured Groundwater Parameters

This study offers a comparative assessment of groundwater quality in the coastal aquifer of Tipo-Tipo, Basilan, under high tide (HT) and low tide (LT) conditions. The results reveal distinct tidal influences on several water quality parameters, particularly those related to salinity, buffering capacity, and mineral content. These findings have serious implications for water security, aquifer vulnerability, and sustainable

resource management, especially for island communities heavily dependent on groundwater.

Salinity and Electrical Conductivity

The electrical conductivity (EC) and total dissolved solids (TDS) increased from 250.88 $\mu\text{S}/\text{cm}$ and 197 mg/L (HT) to 289.28 $\mu\text{S}/\text{cm}$ and 218 mg/L (LT), respectively. It suggests that the aquifer becomes more mineralized during low tide, possibly due to movement of saline water when hydraulic pressure from the sea decreases [4, 10]. While both values remain below the WHO threshold of 500 mg/L TDS, the upward trend is concerning. This salinity fluctuation, currently within safe limits, indicates a tidally driven vulnerability that, if compounded by overpumping, could lead to long-term saline intrusion, compromising water potability [5, 3]. Communities may begin to notice changes in taste or corrosiveness of water even before official thresholds are crossed.

pH, Alkalinity, and Carbonate

Groundwater pH decreased slightly from 8.13 (HT) to 7.9 (LT), still within WHO and PNSDW standards. This shift aligns with the notable increase in total alkalinity (TA) from 23.1 to 184 mg/L, suggesting an enhanced contribution of mineral dissolution, likely from carbonate rocks or shell-rich sediments typical of coastal zones [11]. However, carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) concentrations decreased during LT, which is unexpected. Normally, higher TA is associated with increased HCO_3^- , but its decrease (1.2 to 0.71 mg/L) may indicate dilution with low-alkalinity seawater, a pattern observed in brackish intrusions across tropical coasts [14, 1].

Chloride and Sodium

Among all ions, chloride (Cl^-) showed the most dramatic increase, from 2.2 mg/L (HT) to 21.2 mg/L (LT). This nearly tenfold rise is a direct indicator of tidal salinity intrusion, as Cl^- is a conservative ion that travels with seawater and does not undergo chemical transformation [4, 10].

Sodium (Na^+) levels similarly jumped from 2.7 to 25.3 mg/L, a trend seen in coastal India, Vietnam, and Indonesia, where cations exchange with aquifer materials during seawater mixing [15]. These ions, while still within WHO's 200 mg/L limit, can affect water



palatability and contribute to hypertension risk in sensitive populations when accumulated over time [16].

Calcium, Magnesium, and Potassium: Indicators of Cation Exchange

Levels of calcium (Ca^{2+}) and magnesium (Mg^{2+}) increased markedly during LT, from 1.1 to 7.41 mg/L and 2.6 to 22.1 mg/L, respectively. These trends may result from ion displacement, an indication of cation exchange where Na^+ from seawater replaces Ca^{2+} and Mg^{2+} in aquifer sediments [3, 7].

Potassium (K^+) also increased from 0.1 to 2.59 mg/L, still well below the WHO's 12 mg/L guideline. While K^+ is typically low in seawater, its presence at elevated levels during LT may stem from mineral weathering or minor contributions from anthropogenic sources such as septic leachate or fertilizers [1].

Implication: The enrichment of Ca^{2+} and Mg^{2+} improves water hardness, which may be beneficial for dietary mineral intake, but also increases the potential for scaling in pipes. More importantly, the pattern reflects intensifying subsurface reactions that support the interpretation of early-stage salinization.

Sulfate and Temperature

Sulfate (SO_4^{2-}) remained constant at 10 mg/L in both tidal states, well below the WHO limit of 250 mg/L. This suggests minimal anthropogenic impact, such as fertilizer runoff or industrial waste, common contributors to high SO_4^{2-} in groundwater. Likewise, temperature differences (29.9°C HT vs. 28.6°C LT) were within expected tropical aquifer norms and not considered chemically significant [14].

Saltwater Intrusion

Table 4 indicates how tidal fluctuations affect groundwater chemistry in a coastal aquifer. During high tide, the Mg-SO_4 facie indicates a freshening phase, due to the upward movement of older, less saline water influenced by tidal pressure [17-18].

During low tide, the shift to Mg-Cl facie suggests seawater intrusion, as reduced pressure saline water encroaches inland. Chloride, a conservative tracer, confirms the influence of seawater [19-20].

Similar patterns have been observed globally in tidally influenced aquifers lacking recharge [21-22]. The

transition from Mg-SO_4 to Mg-Cl highlights the aquifer's vulnerability to progressive salinization, emphasizing the need for regular monitoring and sustainable groundwater management [23-24].

Conclusion

This study shows how tides can shape the quality of groundwater in the coastal aquifer of Tipo-Tipo, Basilan. During high tide, the groundwater is relatively less salty and contains lower levels of minerals. But during low tide, the situation changes: saltier and more mineral-rich water moves into the aquifer, as seen in the increases in chloride, sodium, magnesium, and calcium levels.

However, the measured values are still within acceptable limits set by the World Health Organization (WHO) and the Philippine National Standards for Drinking Water (PNSDW).

These findings require regular monitoring and sustainable water management, especially in the coastal aquifer of Tipo-Tipo, which depends heavily on groundwater.

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