



Tidal Variation on the Groundwater Quality of the Coastal Aquifer of Basilan Province, Bangsamoro Autonomous Region in Muslim Mindanao, Philippines

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Abstract:

This study analyzed the physicochemical properties of coastal groundwater, determined the Groundwater Quality Index (GWQI), and assessed saltwater intrusion across the mainland of Basilan Province, Philippines, from May to October 2022. Groundwater samples were collected from 20 wells across nine municipalities and one city during both high and low tides. Parameters such as electrical conductivity (EC), total dissolved solids (TDS), pH, chloride, sulfate, calcium, magnesium, sodium, potassium, carbonate, and bicarbonate were measured using standard analytical techniques. The GWQI was computed using weighted indices based on established guidelines, while saltwater intrusion patterns were evaluated based on dominant ion compositions.

The results revealed significant spatial and tidal variability in water quality. EC ranged from 12.7 to 1790 mg/L at high tide and 15.7 to 1486.8 mg/L at low tide, while TDS increased notably during low tide, peaking at 1840 mg/L. pH values were generally stable (5.3–8.3). Chloride and sulfate concentrations were higher at low tide, while calcium peaked during high tide and magnesium during low tide. Sodium and potassium levels showed minimal tidal variation. GWQI analysis indicated that groundwater in Tuburan, Akbar, Tipo-Tipo, Ungkaya Pukan, and Sumisip was consistently of "Excellent" quality, while Maluso declined from "Excellent" to "Good" during low tide. Lantawan, Albarka, and Lamitan showed mixed water quality, and Moh. Ajul consistently exhibited "Poor" water quality. Saltwater intrusion patterns were categorized as either "Intrusion" or "Freshening," with Tuburan and Moh. Ajul exhibiting stable intrusion conditions, and other areas showing varying transitions due to tidal and hydrogeological influences.

The findings underscore the vulnerability of Basilan's coastal aquifers to seawater intrusion, especially during low tide when dilution is reduced. The consistently poor water quality in Moh. Ajul demands urgent remediation and monitoring. It is recommended that a comprehensive groundwater management plan be implemented, including controlled groundwater extraction, regular water quality monitoring, and community awareness programs to mitigate the long-term impacts of saltwater intrusion and ensure sustainable use of groundwater resources.

1. Introduction

Groundwater, which denotes all the water beneath the ground surface [1], is a vital natural resource that faces significant threats due to various human activities. The quality of groundwater is essential for human survival, the ecological environment, and sustainable regional development [2]. It is increasingly affected by rapid population growth, industrialization, unplanned urbanization, pollution, and excessive use of fertilizers and pesticides in agriculture [3]. In particular, coastal aquifers are important freshwater sources for many

regions [4], and are increasingly threatened by seawater intrusion. These aquifers are characterized by transient water levels, variable salinity, and heterogeneous hydraulic properties, making them highly vulnerable to saltwater intrusion, especially as global sea levels rise [5]. Overexploitation of groundwater in coastal areas exacerbates this issue, drawing saline water from the sea into the aquifers [6].

Saltwater intrusion is a serious concern because 1.5 to 3 billion people rely on groundwater for their daily and economic activities [7]. This natural phenomenon occurs



due to the density difference between seawater and fresh groundwater and is intensified by factors such as tidal processes, precipitation patterns, and freshwater discharge [8-9]. Climate change and sea level rise contribute to increased tidal levels, more intense precipitation, and reduced freshwater discharge, all of which worsen saltwater intrusion [9]. Excessive groundwater extraction further aggravates seawater intrusion and the degradation of water quality in many coastal aquifers [10-11]. The salinization of these aquifers is expected to worsen due to growing demands for freshwater and projected global sea level rise of 0.1 to 2 meters by 2100 [12-13].

Groundwater quality assessment is crucial for effectively utilizing and managing this resource [14]. The physicochemical parameters of water, which vary with geology, depth, and seasonal changes, play a significant role in evaluating water quality [15-16]. The decline in groundwater quality impacts its use for domestic, industrial, and agricultural purposes [17-19], making it a critical issue that requires urgent attention [20-21].

Objectives

The research study aimed to analyze the coastal groundwater quality in terms of its physicochemical properties, categorize the groundwater quality index, and identify the saltwater intrusion

2. Methods

The Study Area

The Basilan Province (Figure 1) has a total area of 137,900 hectares. Geographically, it lies between latitudes 6°16'48" and 6°45'56" North and between longitudes 121°26'00" and 122°24'38" East. The province is composed of two component cities and 11 municipalities with a total of 255 villages. The large island has rolling terrain with flat lands located mostly along the coastal areas. The soil type of Basilan province is mostly of Bulaon clay with a few Bancal clay loam; the province is dominated by agricultural activities. Most areas are planted with coconut, rubber, and other fruit trees. The island has a type IV climate classification, where the seasons are not very pronounced, relatively dry from November to April, and wet during the rest of the year [22]. The annual mean temperature and

precipitation are 26.6 °C and 1,100 mm, respectively [22].

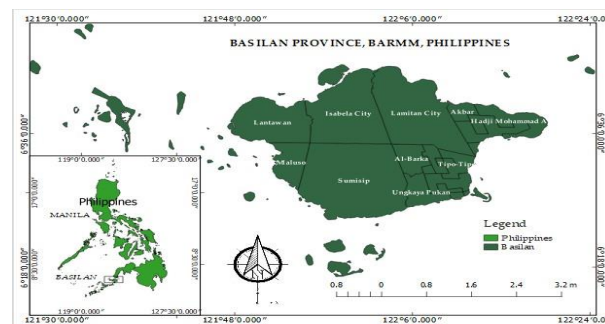


Figure 1. Map of the study area.

Computation of Carbonate and Bicarbonate

Bicarbonate was computed using the equation (Das et al., 2005). $HCO_3^- = 10^{(pH-5.05)}$, while carbonate will be computed using this equation: $Total\ Alkalinity = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] - [H^+]$.

Groundwater quality index

The groundwater Quality Index (GWQI) was calculated using equations [23]. Assigning weights (wi): the most important groundwater quality evaluation parameters, F-, will be assigned with 5, while the least important will be given to Na⁺ and K (Table 2). The categories of the GWQI (Table 1) were adopted for this study.

$$GWQi = \sum n_i Sli$$

$$Sli = Wi \times Qi$$

$$Qi = \frac{Ci}{Si} \times 100$$

$$Wi = \frac{\sum n_i Sli}{i}$$

Where;

Sli sub-index

Wi is the relative weight, wi is the weight of each parameter, and n is the number of parameters

Ci is the concentration of each groundwater quality parameter

Qi is the quality rating

Si is the recommended guideline value for each chemical parameter.



Table 1. Categories Water Quality with the Corresponding Water Quality Index (WQI).

Categories	WQI
Excellent Water	<50
Good Water	50 - 100
Poor Water	100 - 200
Very Poor Water	200 - 300
Water Unsuitable for Drinking	>300

Categories (Ramakrishnaiah et al., 2009)

Table 2. Relative Weight and the Weight of each Parameter.

Parameters	Weight (wi)	Wi
pH	3	0.11
TDS	5	0.18
Chloride	4	0.14
Total Alkalinity	3	0.11
Potassium	2	0.07
Sodium	2	0.07
Magnesium	3	0.11
Calcium	3	0.11
Sulfate	3	0.11
	28	1.00

Sampling and Analysis

The groundwater samples were collected once during high and low tides from twenty (20) existing groundwater wells in nine (9) municipalities and one (1) City. 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

[24] 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 3.

Table 3. Method of Testing of the Groundwater Physico-Chemical Parameters

Parameter	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,
Magnesium	3111 B. Acetylene Flame AAS
Sodium	3030 F. Nitric Acid-Hydrochloric Acid Digestion,
Potassium	3111 B. Direct Air-Acetylene Flame AES
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)

3. Results and Discussions

A. Physico-chemical Component during High and Low Tide

Table 4. Values of different Groundwater Physico-chemical Components in mg/L Measured During High Tide.

Mun.	SW	EC	pH	TDS	Cl	SO4	TA	Ca	Mg	Na	K	CO3	HCO3-
Tuburan	5	184	7.7	224	47.4	10	152	6.2	11.4	28	2.4	8.91E-07	0.4
Akbar	5	34.8	6.4	43	2	11	34.3	0.6	0.5	3.7	1	2.57E-09	0.02
Tipo-Tipo	5	161	8.1	197	2.2	10	23.1	1.1	2.6	2.7	0.1	8.13E-06	1.2
Albarka	4	50.8	7.0	62	10.6	10	98.1	2	4.6	9.5	0.6	3.55E-08	0.08
	5	460	7.6	563	275	38.6	137	3	16.1	146	2.9	7.41E-07	0.36
Maluso	5	12.7	5.4	15	4.5	10	6.95	0.2	0.78	3.6	0.1	2.45E-11	0
	6	13.1	5.9	16	2.9	10	6.9	0.6	0.6	3.6	0.1	2.24E-10	0.01
Lantawan	5	246	7.8	297	12.2	14.4	291	107	14.3	13	1	1.48E-06	0.51
	6	27.9	6.2	27	4.3	10	23.1	2.4	1.2	3.3	0.1	1.12E-09	0.01
Ungkaya Pukan	4	259	7.1	393	46.1	10	261	6.6	18.8	25	1.3	5.89E-08	0.1
	5	176	8.3	275	4.6	10	130	1.9	5.88	11	0.5	1.78E-05	1.78
	6	126	7.5	152	6.2	10	157	7.3	13.6	12	0.5	4.47E-07	0.28
Sumisip	7	143	7.3	175	5.1	10	179	8.2	15.9	14	0.4	1.78E-07	0.18
	8	102	8.0	124	1.9	10	120	5.1	9.1	10	0.3	4.90E-06	0.93
	9	94.6	7.6	112	2.9	10	116	3	7.3	7.3	0.4	7.08E-07	0.35
Moh. Ajul	5	1790	7.6	1270	120	36.3	262	67	16.4	83	6.1	7.08E-07	0.35
	6	134	6.7	164	20.2	10.6	135	8.1	15	18	0.3	1.12E-08	0.04
Lamilan	7	149	7.2	281	21.8	16.2	267	39	26.4	44	0.3	1.12E-07	0.14
	8	344	8.0	419	75.6	15.8	356	41	36.6	57	2.9	4.47E-06	0.89
	9	248	7.8	302	7.3	16.6	301	87	13.8	11	1.1	1.48E-06	0.51



Electrical Conductivity (EC)

The electrical conductivity (EC) ranged from 12.7 -1790 mg/L (Table 4) during high tide and 15.7-1486.8 mg/L during low tide (Table 5). The EC content of the coastal groundwater of Moh. Ajul municipality was higher compared to the rest of the areas; meanwhile, Maluso was recorded as low EC. The municipality of Moh. Ajul has the highest EC value on both tides; however, it is substantially higher during the high tide. It indicates that the coastal groundwater of Moh. Ajul has a higher number of impurities compared with the rest of the areas.

Total Dissolved Solids (TDS)

The TDS ranges from 15 mg/L (Maluso) to 1270 mg/L (Moh. Ajul) (Table 4) during the high tide, and ranges from 19.3 mg/L (Maluso) to 1840 mg/L (Moh. Ajul) (Table 5) during the low tide. TDS is generally higher during low tide compared to high tide. This suggests that higher concentrations of dissolved substances accumulate during low tide, possibly due to reduced dilution effects or increased inflow of groundwater with higher TDS. As the tide recedes, groundwater might flow more significantly into the tidal zone, contributing to the higher TDS levels observed.

pH

The pH ranges from 5.4 (Maluso) to 8.3 (Ungkaya Pukan) (Table 4) and ranges from 5.3 (Maluso) to 8.3 (Sumisip) (Table 5). The pH values are similar between high and low tides, indicating that tidal changes have minimal impact on the water's acidity or alkalinity. It implies that the processes affecting pH, such as acidification or alkalization, are not strongly linked to tidal movements. It could be due to the buffering capacity of the water body or the lack of significant pH-altering inputs from tidal actions.

Chloride (Cl)

The Cl ranges from 2 mg/L (Akbar) to 275 mg/L (Albarka) (Table 4) and ranges from 1.5 mg/L (Akbar) to 270 mg/L (Albarka) (Table 5). Chloride levels are consistent between the two tidal conditions. This stability indicates that chloride levels are not significantly influenced by tidal fluctuations. Chloride levels are consistent across tidal stages but are at the higher end of the range during low tide. It indicates that while tidal changes do not influence chloride levels, the overall

concentration of chloride increases during low tide due to less dilution or concentrated inflow.

Sulfate (SO₄)

The sulfate ranges from 6.9 mg/L (Maluso) to 291 mg/L (Lantawan) (Table 4) and ranges from 9.2 mg/L (Maluso) to 356 mg/L (Lamitan) (Table 5). Sulfate levels tend to be higher during low tide compared to high tide, suggesting that sulfate concentrations might increase due to reduced dilution or additional sources during low tide. On the other hand, Maluso's groundwater was considered clean based on the EC values. Sulfate concentrations are generally higher during low tide, similar to TDS and EC. It suggests that sulfate levels might increase during low tide due to changes in groundwater flow or concentration effects.

Calcium (Ca)

The Ca ranges from 0.2 mg/L (Maluso) to 107 mg/L (Lantawan) (Table 4) and ranges from 2.1 mg/L (Albarka) to 87 mg/L (Lamitan) (Table 5). Calcium concentrations are generally higher during high tide. It is due to variations in groundwater recharge rates or the dissolution of calcium-containing minerals during periods of increased tidal influence, and accumulation of these minerals in groundwater dilution or changes in groundwater flow patterns.

Magnesium (Mg)

The Mg ranges from 0.6 mg/L (Maluso) to 36.6 mg/L (Lamitan) (Table 4) and ranges from 0.9 mg/L (Akbar) to 54.9 mg/L (Lamitan) (Table 5). Magnesium concentrations are higher during low tide. It reflects increased groundwater inputs or mineral dissolution during low tide periods.

Sodium (Na)

The Na ranges from 0.5 mg/L (Akbar) to 83 mg/L (Moh. Ajul) (Table 4) during the tide and ranges from 0.5 mg/L (Akbar) to 73.4 mg/L (Moh. Ajul) (Table 5) during the low tide. Sodium levels are relatively stable, with slight variations between high and low tides. Sodium concentrations are higher during low tide, which might be due to increased groundwater flow or reduced dilution, leading to higher concentrations of sodium.



Potassium (K)

The K ranges from 0.1 mg/L (Maluso) to 6.1 mg/L (Moh. Ajul) (Table 4) during high tide, and ranges from 0.3 mg/L (Sumisip) to 5.9 mg/L (Moh. Ajul) (Table 5) during low tide. Potassium levels are quite stable, with minimal variation between high and low tides.

Carbonate (CO₃) and Bicarbonate (HCO₃⁻)

The CO₃ ranges from 0 (Maluso) to 1.48E-06 (Lantawan), and HCO₃ ranges from 0 (Maluso) to 1.20 (Tipo-Tipo) (Table 5) during the high tide, and CO₃ ranges from 1.78E-06 (Sumisip) to 4.90E-05 (Sumisip), and HCO₃ ranges from 0 (Maluso) to 1.82 (Sumisip) (Table 5) during the low tide. Carbonate concentrations are generally low and don't show significant variation between high and low tides. Bicarbonate levels, however, exhibit some variability, with higher concentrations observed during low tides.

Table 5. Values of different Groundwater Physico-chemical Components in mg/L Measured During Low Tide.

Mun	SW	EC	pH	TDS	Cl	SO ₄	TA	Ca	Mg	Na	K	CO ₃	HCO ₃ ⁻
Tuburan	5	184.3	7.8	223	47.9	10	152	6.6	12.6	30.4	2.4	1.62E-06	0.54
	5	256.0	6.8	387	1.5	10.5	35.4	0.6	0.9	4.1	1.0	1.78E-08	0.06
Tipo-Tipo	5	185.1	7.9	218	21.2	10	184	7.4	22.1	25.3	2.6	2.82E-06	0.71
	4	51.2	7.5	61	11.4	10	92.1	2.1	4.7	8.8	0.5	4.47E-07	0.28
Albarka	5	417.4	7.6	556	270	36.8	139	3.2	17.2	155	2.9	7.08E-07	0.35
	5	15.7	5.6	19.3	88.1	10	9.2	16.4	8.6	38.2	0.1	7.41E-11	0.00
Maluso	6	26.8	5.3	32.9	139	500	13.9	33.7	21.0	43.4	0.3	1.86E-11	0.00
	5	260.9	7.8	311	17.4	15.8	349	74.8	17.9	18.2	3.7	1.86E-06	0.58
Lantawan	6	23.3	5.9	16	6.2	10	23	0.9	2.0	3.7	0.2	2.34E-10	0.01
	4	269.1	7.8	361	45.1	10	257	6.8	17.0	27.9	1.4	1.78E-06	0.56
Ungkaya Pukan	5	184.7	7.8	233	4.3	10	140	1.9	5.9	10.3	0.5	1.78E-06	0.56
	6	153.6	7.6	165	5.8	10	161	6.2	10.3	9.3	0.5	7.08E-07	0.35
Sumisip	7	143.0	7.3	173	5.1	10	182	7.6	14.3	12.6	0.4	1.62E-07	0.17
	8	99.1	8.3	120	3.9	10	121	5.1	10.0	10.7	0.3	1.86E-05	1.82
Moh. Ajul	9	94.2	7.7	114	1.9	10	123	3.0	7.7	7.9	0.4	1.12E-06	0.45
	5	1486.8	8.1	1840	115	36.8	266	61.7	15.7	73.4	5.9	5.89E-06	1.02
Lamitan	6	136.8	6.7	167	20	10	130	7.8	15.0	18.3	0.2	1.12E-08	0.04
	7	236.7	7.3	287	17.2	15.4	169	24.9	15.6	16.8	0.3	1.78E-07	0.18
Lamitan	8	343.2	8.0	419	73.1	11.6	320	46.5	35.4	54.9	2.9	4.47E-06	0.89
	9	249.4	7.7	303	6.8	10.8	305	90	14.4	11	1.0	1.12E-06	0.45

B. Groundwater Quality Index (GWQI)

Based on Tables 1 and 6, the groundwater of the municipalities Tuburan, Akbar, Tipo-Tipo, Ungkaya Pukan, and Sumisip in all sampling wells maintains consistently excellent water quality during high and low tides, while Maluso maintains "Excellent Water" quality at high tide but shows a decline to "Good Water" at low tide in sampling well (SW6). This indicates a potential

decrease in water quality during low tide, though it remains relatively low. However, the groundwater of Lantawan, Albarka, and Lamitan shows sets of GWQI values. The first set indicates "Excellent Water" quality at both high and low tides, whereas the second set indicates "Good Water" quality at both, it indicates variability in groundwater quality, potentially influenced by specific local conditions. On the other hand, the groundwater of Moh. Ajul has consistently poor water quality, with GWQI values indicating "Poor Water" at both high and low tides. This suggests serious water quality issues that require attention.

Table 6. Type of Water Based on Computed GWQI, Both High and Low Tides Per Sampling Well Per Municipality.

Municipality	SW	Longitude	Latitude	GWQI	Categories
Tuburan	1	122.1892	6.61733	76.76	Good Water
	2	122.1916	6.61013	78.86	Good Water
	3	122.1889	6.61504	97.06	Good Water
	4	122.2009	6.61176	73.91	Good Water
Akbar	1	122.1951	6.66579	83.74	Good Water
	2	122.1851	6.66492	87.93	Good Water
	3	122.1831	6.64986	74.72	Good Water
	4	122.1835	6.62245	85.83	Good Water
Tipo-Tipo	1	122.1241	6.51318	73.76	Good Water
	2	122.2007	6.53491	40.68	Excellent Water
	3	122.1554	6.55801	79.58	Good Water
	4	122.1742	6.57503	76.71	Good Water
Albarka	1	122.1506	6.49731	74.09	Good Water
	2	122.1499	6.4742	75.28	Good Water
	3	122.1333	6.46016	79.50	Good Water
Maluso	1	121.8911	6.55889	74.48	Good Water
	2	121.8898	6.51929	72.64	Good Water
	3	121.9146	6.50708	75.19	Good Water
	4	121.9134	6.48632	75.10	Good Water
Lantawan	1	121.9271	6.59682	73.88	Good Water
	2	121.8558	6.60375	74.78	Good Water
	3	121.8407	6.63623	64.73	Good Water
	4	121.8769	6.64663	59.06	Good Water
Ungkaya Pukan	1	122.1065	6.46004	77.53	Good Water
	2	122.1171	6.49126	41.08	Excellent Water
	3	122.1265	6.52147	84.31	Good Water
Sumisip	1	122.0536	6.44591	64.42	Good Water
	2	122.0297	6.43494	80.37	Good Water
	3	122.0091	6.42705	81.92	Good Water
	4	121.9775	6.43197	80.06	Good Water
	5	121.9552	6.44956	85.47	Good Water
Moh. Ajul	1	122.2548	6.64675	79.71	Good Water
	2	122.2569	6.64575	74.35	Good Water
	3	122.2666	6.64065	76.18	Good Water
	4	122.2704	6.64077	81.23	Good Water
Lamitan	1	122.035	6.69555	31.11	Excellent Water



Table 7. Phases of Coastal Groundwater of Basilan During High and Low Tides.

Mun.	SW	High Tide		Low Tide	
		Phase	Water Type	Phase	Water Type
Tuburan	5	Intrusion	Na Cl	Intrusion	Na Cl
Akbar	5	Freshening	Na SO4	Freshening	Na SO4
Tipo-Tipo	5	Freshening	Mg SO4	Intrusion	Mg Cl
Albarka	4	Intrusion	MixNa Cl	Intrusion	MixNa Cl
	5	Freshening	Na Cl	Freshening	Na Cl
Maluso	5	Freshening	Na SO4	Intrusion	Na Cl
	6	Freshening	Na SO4	Freshening	MixNa SO4
Lantawan	5	Intrusion	Ca Cl	Intrusion	Ca Cl
	6	Freshening	MixNa SO4	Freshening	MixNa SO4
Ungkaya Pukan	4	Intrusion	Mg Cl	Intrusion	MixMg Cl
	5	Freshening	MixNa SO4	Freshening	MixMg SO4
Sumisip	6	Intrusion	Mg SO4	Intrusion	Mg SO4
	7	Freshening	Mg SO4	Intrusion	Mg SO4
	8	Freshening	Mg SO4	Freshening	Mg SO4
	9	Freshening	Mg SO4	Freshening	Mg SO4
Moh. Ajul	5	Intrusion	MixNa Cl	Intrusion	MixNa Cl
Lamitan	6	Intrusion	Mg Cl	Intrusion	Mg Cl
	7	Intrusion	MixMg Cl	Intrusion	MixMg Cl
	8	Intrusion	MixMg Cl	Intrusion	MixMg Cl
	9	Intrusion	Ca SO4	Intrusion	Ca SO4

C. Saltwater Intrusion

According to Table 7, the coastal groundwater exhibits a consistent "Intrusion" pattern at both high and low tides, as shown in Figure 3 in Tuburan and Moh. Ajul, where Sodium (Na) and Chloride (Cl) are the predominant ions, indicating stable seawater intrusion throughout the tidal cycle, whereas Lamitan City shows variability with Magnesium (Mg) and Chloride (Cl) at sampling well (SW6), mixed Magnesium (MixMg) and Chloride (Cl) at SW7 and SW8, and Calcium (Ca) with Sulfate (SO₄) at (SW9), reflecting fluctuating seawater influence; similarly, Albarka maintains "Intrusion" with mixed Sodium (Na) and Chloride (Cl) ions at SW4 but shows "Freshening" with Sodium (Na) and Chloride (Cl) at SW5, suggesting potential periods of recharge or changes in groundwater composition; Lantawan consistently displays "Intrusion" with Calcium (Ca) and Chloride (Cl), indicating stable seawater intrusion, though there are occasional "Freshening" periods with mixed Sodium (Na) and Sulfate (SO₄), suggesting occasional fresh recharge; Ungkaya Pukan shows consistent "Intrusion" with Magnesium (Mg) and Chloride (Cl), with variations in Magnesium ion

concentrations, and periods of "Freshening" with mixed Sodium (Na) and Sulfate (SO₄) or Magnesium (Mg) and Sulfate (SO₄), indicating some fresh water recharge; Sumisip consistently demonstrates "Intrusion" with Magnesium (Mg) and Sulfate (SO₄) at both tides, reflecting stable seawater influence, though there are periods of "Freshening" with the same ions, suggesting seasonal or tidal variations; in Akbar, the groundwater is characterized by "Freshening" at both tides with Sodium (Na) and Sulfate (SO₄) as the dominant ions, indicating minimal seawater intrusion and a predominance of fresh water recharge; Tipo-Tipo transitions from "Freshening" at high tide with Magnesium (Mg) and Sulfate (SO₄) to "Intrusion" at low tide with Magnesium (Mg) and Chloride (Cl), reflecting tidal shifts in groundwater composition; and Maluso's groundwater shifts from "Freshening" at high tide with Sodium (Na) and Sulfate (SO₄) to "Intrusion" at low tide with Sodium (Na) and Chloride (Cl), indicating fluctuating influences from seawater and fresh water sources.

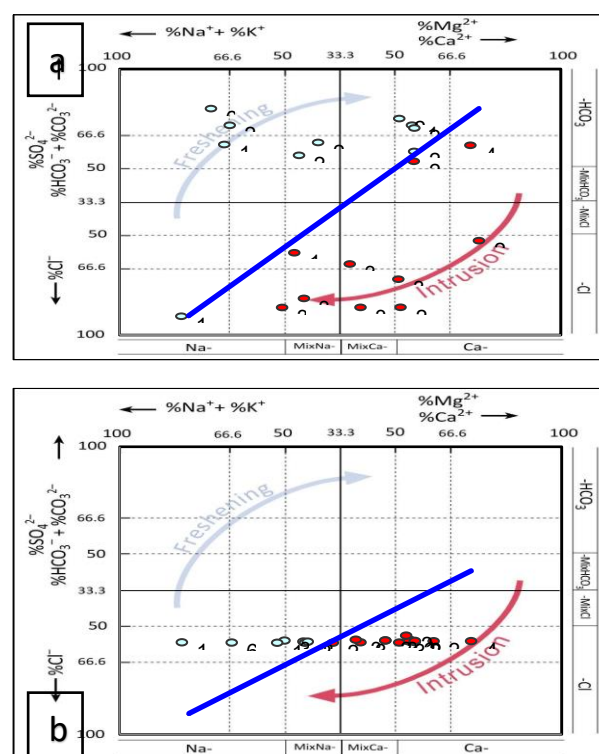


Figure 2. HFE-D Diagram Showing the Intrusion and Freshening of Groundwater Coastal During, a. High tide, and b. Low Tide, October 2022.



Conclusion

The coastal groundwater exhibits significant variability in quality across different parameters. Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are highest at Moh. Ajul indicates greater impurity levels, particularly during high tide. TDS generally increases during low tide due to reduced dilution. pH levels remain stable regardless of tidal changes, suggesting minimal impact from tidal movements. Chloride levels are consistent across tides but are higher during low tides. Sulfate concentrations also rise during low tide, reflecting changes in groundwater flow. Calcium levels peak during high tide, while magnesium is higher during low tide. Sodium levels are stable but increase slightly during low tide. Potassium remains relatively constant. Carbonate levels are low with minimal variability, while bicarbonate levels increase slightly during low tide.

The GWQI of Tuburan, Akbar, Tipo-Tipo, Ungkaya Pukan, and Sumisip consistently maintains excellent groundwater quality at both high and low tides. Maluso shows a decline from "Excellent" to "Good" quality during low tide. Lantawan, Albarka, and Lamitan exhibit variability, with some wells showing "Excellent" and others "Good" quality. Moh. Ajul consistently has poor water quality, indicating serious concerns that need addressing.

Coastal groundwater shows stable "Intrusion" patterns at Tuburan and Moh. Ajul, with predominant Sodium (Na) and Chloride (Cl) throughout tides. Lamitan exhibits variability with different ions, indicating fluctuating seawater influence. Albarka and Lantawan also show "Intrusion" but with occasional "Freshening" periods, suggesting intermittent recharge. Ungkaya Pukan and Sumisip display consistent "Intrusion" with periods of "Freshening." Akbar consistently shows "Freshening," indicating minimal seawater intrusion. Tipo-Tipo and Maluso experience shifts between "Freshening" and "Intrusion," reflecting tidal changes and variable influences from seawater and freshwater sources.

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