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Assessment of Saltwater Intrusion Using Geochemical Chloride Bicarbonate Ratio Method in Cagayan de Oro City, Philippines

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Abstract

Groundwater is a common source of water in developing countries. However, these resources experienced significant pollution from anthropogenic activities, which affects the ability of these resources to support life. In the Philippines, numerical modeling is ubiquitously associated with saltwater intrusion (SWI), while the geochemical approach was documented to be considered scarce. This study attempted to document SWI in Cagayan de Oro using the geochemical chloride-bicarbonate ratio method. Influence of tidal fluctuations SWI, as well as determining the factors that are associated with SWI were statistically determined. While most of the groundwater wells were still considered normal, data shows that 3 of these were already intruded by saltwater. Particularly, the western coastal realms of the city including barangay Bulua, and Kauswagan recorded SWI values that are 51% greater than the SWI average of the city. Tidal oscillation was similarly found to statistically affect SWI, where records on high tide events showed 23% greater than on low tide phenomena. This study further revealed that inherent topographic characteristics of a landscape affect the occurrence of SWI. In particular, areas characterized by flat slopes, low elevation, and in close proximity to the coast statistically showed positive responses to that of the SWI ratio, implying that SWI may likely ameliorate if a landscape may exhibit those aforementioned characteristics. Emphasis on creating effective monitoring strategies is recommended to ensure the sustainability of groundwater resources of the city.

Keywords: Cagayan de Oro; Groundwater Quality; Hydrochemistry; Saltwater intrusion

1. Introduction

Conservation of coastal aquifers is necessary as it serves as the main source of freshwater demands for global coastal communities (Alfarrah and Walraevens, 2018; Barlow and Reichard, 2009). The relevance of effective coastal aquifers conservation is becoming more serious considering that most of the densely populated cosmopolitan areas and economically-valuable economic districts are positioned in coastal areas, necessitating the need to urgently characterize the status and quality of coastal aquifers (Safi *et al.,* 2018). Despite the great importance of aquifers in sustaining and advancing the economies of coastal communities, continued anthropogenic interference and unintended coastal hydrological system modifications significantly induced pollution of groundwater quality by saltwater transport, deposition, and intrusion.

Relevant examinations that would understand the dynamics of saltwater intrusion are necessary to promote and accelerate effective conservation measures of groundwater resources. Mathematical models have been utilized to produce results, and project the future scenarios of saltwater intrusion (SWI) via assimilation of contemporary empirical data (Abd-Elaty *et al.,* 2019).

Despite the promising results demonstrated by this approach, it is apparent that it is restrained by the availability of continuous field measurement, making it less feasible if applied in a larger geographic area. This type of modeling predicament is underscored in the study of El Hamidi *et al.,* (2021), where they postulated that despite their model performing and yield with accurate results, the paucity of long-term in-situ measurements, coupled with the absence of other sophisticated field parameters limits the reliability of the model.

Investigating the extent of SWI is gaining popularity in the Philippines owing to the burgeoning water resource demand in the country. Although widespread, existing literature focusing on SWI in the Philippines used indirect methods, specifically geophysical and geographic modeling approaches (Ngilangil *et al.,* 2018). While such an approach may determine the conditions of groundwater, and could greatly explain the dynamics of saltwater intrusion, it is therefore worth noting that understanding the occurrence of SWI remained to be a context-specific endeavor, which could only be satisfied via direct in-situ geochemical characterization (Prusty and Farooq, 2020).

In 1991, the Japan International Cooperation Agency (JICA) stressed that most of the major cities in the Philippines including Cagayan de Oro City illustrate the condition of becoming a water-scarce areas. This is reflected in the results of Palanca-Tan (2011) where the study showed that the withdrawal rates recorded a total of 3.3 million m^3 $month^{-1}$ in 2000, while 4.7 million m^3 $month^{-1}$ in 2011, representing a total increase of 42% in 10 years. This is further exacerbated by the conditions that groundwater extraction was found to be unregulated, and understudied (Racadio *et al.,* 2020). Despite the presumed severity of saltwater intrusion in Cagayan de Oro City, published articles that examine groundwater quality in Cagayan de Oro have only documented the quality of the city's groundwater resources (Palanca-Tan 2011). Factors affecting SWI has been thoroughly reviewed in (Prusty and Farooq, 2020), where it was mentioned that topographic characteristics, human activities, and tidal actions can influence SWI, however, these factors still remained undocumented in Cagayan de Oro. Overall, these data gaps suggested the need to carry out a study on SWI and groundwater quality in the coastal areas in Cagayan de Oro City. In this study, a geochemical characterization approach was carried out to determine the SWI and the corresponding water quality status of coastal groundwater resources of Cagayan de Oro City. Geochemical characterization provides a straightforward result that illustrates the severity of saltwater intrusion in the coastal regimes of the city. Also, application of statistical tools was undertaken to elicit relationships of topographic and water quality towards SWI. Moreover, this also highlights the novelty of the study considering that majority of saltwater intrusion studies existing in the Philippines concentrated on remote sensing, and GIS-based SWI modeling (Ng *et al.,* 2018; Ngilangil *et al.,* 2018), where the quality of the result is highly dependent on field-based measurements.

2. Methodology

2.1 Description of the study area

This study was conducted in Cagayan de Oro City, a first-class highly urbanized district that falls under the provincial administrative domain of Misamis Oriental, Philippines (Figure 1). The city is known as the capital of the Misamis Oriental where it accommodates a plethora of industrial zones and human resource industries. Recent population census data released by the Philippine Statistics Authority (PSA) suggests that the city exhibited the highest population in the province with an estimated population of about 728,402, illustrating a net growth rate of 1.58% relative to the 2015 population survey. This increase in population may indicate an intensification of pressure on the groundwater resources of the city due to burgeoning demands for freshwater. Despite the increasing threats to the groundwater resources in the city, the availability of groundwater quality data is seldom discussed in Cagayan de Oro City, with the recent one was previously conducted in 2003. Moreover, such analyses that were previously carried out were limited to those deep wells that were legally registered, while directly disregarding wells that were illegally constructed. The geographic position of the Cagayan de Oro is subdivided by a huge river cutting across the central district, distinctively creating two administrative districts, specifically district 1 (western coast), and district 2 (eastern coast). In this study 4 groundwater wells were located in the western coast, while the rest were located in the eastern coast, respectively.

2.2 Sample collection and analysis

A total of 23 groundwater sites located in Cagayan de Oro were sampled in May 2022. The collection of samples was simultaneously performed to eliminate potential variability that may arise from varying temporal conditions of water collection. Prescribed protocols for groundwater sampling and storing were done during sample collection. Specifically, 500 ml sterilized low-density polyethylene bottles were rinsed with groundwater before sample collection. Physical characteristics including pH, temperature, TDS, salinity, and electrical conductivity were determined in situ using multiparameter probes. All groundwater samples were contained in a pre-condition ice chest that had been set to a temperature of 4 °C. Carbonates and bicarbonate concentrations of groundwater samples were analyzed using a titrimetric method, while chloride was measured using argentometric method (APHA, 1995). Both of which had a detection limit of 1.0 mg/L. Errors of all the analytical analyses were found to be within the tolerable limit of 5%, thus confirming the acceptability of the analytical results.

2.3 Saltwater intrusion

The status of saltwater intrusion in Cagayan de Oro was determined using chloride-bicarbonate ratio method described in Panjaitan *et al.,* (2018). Ratio quantification was calculated following equation 1. Descriptive stratification was deduced based on Simpson's index similarly presented in Panjaitan *et al.* (2018) (Table 1).

$$SWI = \frac{Chloride\ (\frac{mg}{L})}{Bicarbonate + Carbonate}$$

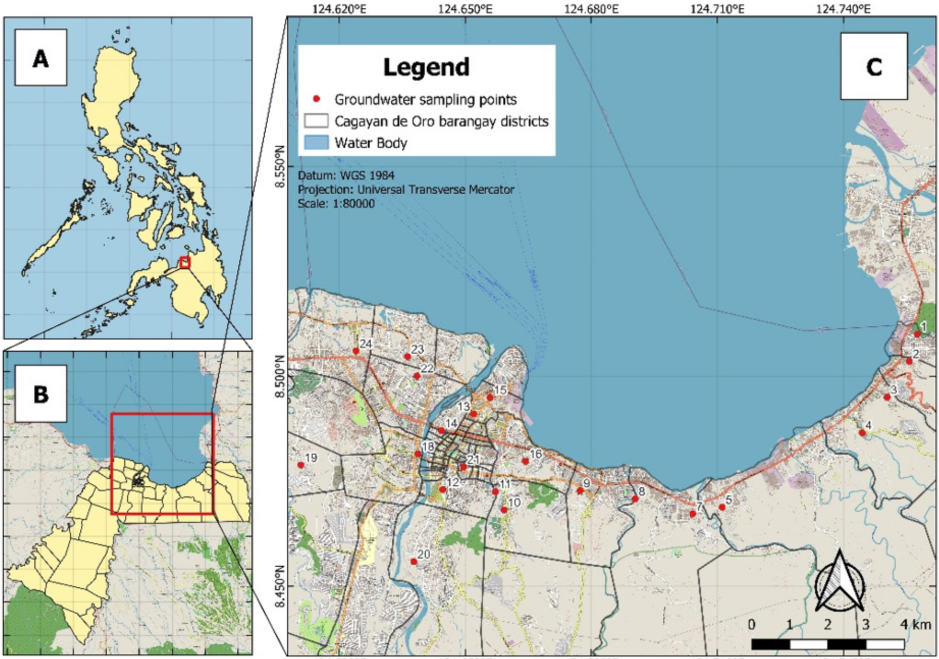

Figure 1. Illustration of study site showing the geographic extent of: A) The Philippines, B) Cagayan de Oro City, C) Distribution of groundwater sampling stations along the coast of Cagayan de Oro City

Table 1. Location of each groundwater sampling site

SWI Status Classification	Saltwater Intrusion Numerical Range
Normal	< 0.5
Low	0.5 - 1.3
Moderate	1.3 - 2.8
Rather High	2.8 - 6.6
High	6.6 -15.5
Seawater	> 15.5

Table 2. Categorical stratification of SWI status based on geochemical Chloride Bicarbonate Ratio Method

ID	Groundwater Sites	Distance from the Coast [m] [a]	Elevation [m] [b]	Slope [%] [b]
1	Zone 5, Bugo	584	5	2.81
2	Bantilis, Bugo	448	7	8.52
3	Mahayahay, Agusan	576	12	1.32
4	Teakwood, Agusan	802	13	10.52
5	Villaverde, Tablon	795	8	1.32
6	Talidhay, Cugman	650	10	2.09
7	Villa Ernesto, Gusa	933	6	2.08
8	JR Borja Street	507	8	4.65
9	Bontong, Camaman-an	817	16	4.65
10	Adella, Camaman-an	1860	10	2.96
11	Sportzone, Nazareth	1764	10	5.9
12	Baculio Street, Brgy. 21	1224	5	1.32
13	Abellanosa Street, Brgy. 17	1281	6	5.68
14	Corrales	2178	6	5.63
15	Hillside, Lapasan	868	9	8.29
16	Urban, Iponan	3545	8	2.08
17	Vamenta Blvd., Carmen	3545	9	2.09
18	Sunrise Village, Patag	6317	20	2.07
19	Tibasak, Macasandig	6317	9	2.8
20	Barangay 32	3458	7	1.85
21	DMCC, Kauswagan	1388	5	2.09
22	Capisnon, Kauswagan	1156	5	2.93
23	Saarenas, Bulua	1316	5	0.93

Note: Selection of deep wells was randomly done during field reconnaissance.

[a] Distance from the coast was calculated from Google Earth Pro.

[b] Slope and elevation were calculated from NASA-DEM raster file.

2.4 Data analysis

Statistical differences between tide oscillations were evaluated using t-test assuming unequal variance. Factors affecting the SWI were statistically explored using Pearson's Correlation test. Association was further determined using a multiple linear regression model with backward elimination method. Iterations of model implementation were conducted until all variables exhibited significant relationship towards the SWI values. Overall, these statistical analyses were carried out at a 95% confidence level.

3. Results and Discussion

3.1 Groundwater quality

Table 3 summarizes the physicochemical characteristics of groundwater in Cagayan de Oro. pH values did not exhibit predictable trends as it had a range of 6.63 - 7.34 in low tide with a mean pH of 6.96, while 6.11 - 7.47 during high tide recording an average value of 6.74. Comparison between tide oscillation showed statistical differences (*$p < 0.05$*) in terms of their pH. This range is typical in shallow groundwater as it may be governed by carbonic equilibrium, a groundwater change mechanism that modifies pH values as a function of varying CO_2 and HCO_3^- concentrations (Zhou *et al.,* 2015). Concentration of CO_2 may dissolve in groundwater, which may culminate in the production of H_2CO_3. Hydrolysis of H_2CO_3 may produce HCO_3^- and H^+ ions while spontaneously discarding H^+ ions, making groundwater acidic.

Measurements of salinity were greater during high tide with 16 groundwater sampling sites charted with higher high tide values compared to low tide. Salinity from low tide has a range of 129.00 - 804.67 ppm illustrating an average of 492.38 ppm. On the other hand, Salinity from high tide recorded a minimum of 127.33 ppm and a maximum of 804.67 ppm showing an average of 847.33 ppm. This tidal-associated dichotomy further shows that it has an average difference of 12.125 ppm and a maximum difference of 48.67 ppm. Despite apparent differences relative to the tidal fluctuation, this observation showed no significant difference in salinity observed between tide intervals. Moreover, the range obtained from in-situ analysis of salinity collectively suggests low salt enrichment (< 1,500 uS) (Sarath Prasanth *et al.,* 2012).

Total Dissolved Solids (TDS) showed higher values in low tide events with a mean TDS value of 657.43 ppm, whereas high tide illustrated a mean value of 648.81 ppm, respectively. Similarly, we found that the concentration of dissolved solids may be positively associated with the distance from the coast (*p-value < 0.05*). Irrespective of tide oscillations, 85% of the total groundwater well counts were still considered freshwater (TDS < 1000 ppm), while the remaining 15% are considered slightly saline water (TDS 1000 - 3000 ppm) according to freeze and cherry classification (Krishnakumar *et al.,* 2014). Classification of water outlined in Davis and De West (1966) corroborated that 23% of groundwater is still suitable for drinking (< 500 ppm), while the rest may be used for irrigation (1000 - 3000 ppm).

Notably, distance from the coast slightly affects EC, salinity, TDS, and alkalinity (Table 4), indicating that dissolved ions enrichment may be of greater proportion in areas situated far from the coast. The concentration of chloride exhibited an inversely proportional relationship, corroborating that the concentration of chloride may likely decrease as the distance from the coast increases.

3.2 Saltwater intrusion (SWI)

The SWI of groundwater in Cagayan de Oro City is shown in figure 2. Measurements of SWI ratio during low tide ranged from 0.05 - 0.25, with a mean value of 0.10, while high tide has a range of 0.05 - 0.54, charting a mean SWI ratio of 0.17 (table 5). Data further corroborated statistical differences between high tide and low tide SWI measurements (*p-value < 0.05*). Moreover, SWI measurements of Cagayan de Oro is significantly lower compared to Belawan Indonesia (Panjaitan *et al.,* 2018), and Damghan, Iran (Ebrahimi *et al.,* 2016) where it had a percent difference of 98% and 97%, respectively.

While 20 of the groundwater wells (86%) are still considered normal, it is alarming that 3 of these were found to record elevated chloride concentration, a groundwater quality that is commonly associated with saltwater intrusion. Most of the western coast barangays of the city including Bulua, Bayabas, Kauswagan, Bonbon, and a portion of Mideastern barangays including eastern Gusa alarmingly exhibited elevated SWI values during high tide events. Particularly, these barangays alone recorded an SWI ratio of 0.51, a value that is 51% higher than the city's average. It is evident that massive water withdrawal from these deep wells may likely influence the occurrence of SWI. In particular, deep well in Bulua (station 23) served as the secondary source of domestic water for 15 different families, the highest number of users among all stations established (Ebrahimi *et al.,* 2018).

Table 3. Physical characteristics of groundwater in Cagayan de Oro City, Philippines

Groundwater ID	pH		EC [a, c]		Salinity [b, c]		TDS [b, c]		Chloride [b, c]		Alkalinity [b, c, d]	
	Low tide	High tide	Low tide	High tide	Low tide	High tide	Low tide	High tide	Low tide	High tide	Low tide	High tide
1	7.00	7.47	1215.67	1218.33	613.67	617.67	851.67	823.33	60.34	64.43	462.8	418.32
2	7.18	7.01	800.33	806.33	401.33	405.00	532.00	550.33	20.66	20.17	368.85	374.04
3	7.14	6.63	255.33	257.33	129.00	127.33	168.00	174.33	10.19	10.16	100.05	115.2
4	6.81	6.61	327.67	330.33	163.33	164.67	216.33	225.00	16.93	16.07	110.42	114.48
5	6.71	6.86	1185.00	1190.00	590.67	607.33	785.33	813.67	57.55	42.79	431.6	391.68
6	6.85	6.89	1262.00	879.33	636.33	441.67	845.67	591.00	36.5	49.84	380.99	295.22
7	6.92	6.85	1235.67	1255.33	618.00	631.00	823.33	844.33	66.09	66.4	380.64	202.44
8	6.94	6.92	921.33	925.67	461.33	463.00	611.33	616.67	19.73	51.48	319.28	309.96
9	6.68	6.76	840.33	850.00	425.67	424.00	567.33	573.00	35.18	40	380.64	277.56
10	6.78	6.91	1028.00	1030.33	517.33	520.33	688.00	685.33	35.68	34.43	385.61	361.8
11	6.96	6.93	1002.00	1015.33	504.33	501.67	669.00	670.33	45.38	29.67	365.35	303.84
12	7.19	7.05	1600.67	1606.33	804.67	812.00	1067.67	1073.67	36.17	30.42	634.06	624.6
13	7.18	7.19	711.67	708.33	360.33	350.67	475.00	475.33	24.99	22.52	284.76	280.15
14	7.04	7.07	862.33	858.33	435.00	429.00	571.00	568.00	30.09	32.06	356.76	391.32
15	7.04	7.03	1102.00	1131.00	551.33	570.00	732.33	755.00	24.99	28.94	410.8	633.24
16	6.78	6.28	1541.33	1487.67	771.67	769.00	1044.00	1010.00	33.71	53.11	632.23	402.12
17	6.64	6.11	790.67	820.33	391.67	406.33	520.00	546.67	33.87	52.45	265.65	402.12
18	6.87	6.38	729.67	706.33	360.67	354.67	483.33	479.00	28.61	28.53	310.96	292.24
19	6.63	6.29	1457.67	1444.33	716.33	733.00	972.33	964.67	31.73	64.43	451.41	412.19
20	7.34	6.66	1016.67	1017.67	507.67	500.00	687.33	686.00	26.31	50.17	397.08	340.08
21	7.13	6.26	716.00	728.33	353.00	361.00	485.33	482.33	24.5	38.36	282.53	276.99
22	7.08	6.34	646.67	484.67	326.67	243.67	437.33	319.33	39.62	38.53	356.04	151.15
23	7.05	6.27	1658.00	1694.67	864.50	847.33	1164.50	1146.67	151.26	190.18	594.37	591.41
min	6.63	6.11	255.33	257.33	129.00	127.33	168.00	174.33	10.19	10.16	100.05	114.48
max	7.34	7.47	1658.00	1694.67	864.50	847.33	1164.50	1146.67	151.26	190.18	634.06	633.24
mean	6.95	6.73	995.94	975.93	500.20	490.45	669.49	655.39	38.70	45.88	376.65	346.18

EC, Electrical Conductivity; TDS, Total Dissolved Solids.

[a] Measurement was expressed in terms of uS/cm.

[b] Measurement was expressed in terms of parts per million (ppm).

[c] In-situ measurements of these parameters were done within 24-hour observations.

[d] Alkalinity is the sum of HCO_3^- and CO_3^{2-}.

Table 4. Correlation matrix of variables derived from Pearson's correlation analysis

	Distance from the Coast	pH	EC	Salinity	TDS	Cl	Alkalinity
distance from the coast	1.00000						
pH	-0.31704	1.00000					
EC	0.16603	-0.13981	1.00000				
Salinity	0.14579	-0.12646	0.99911	1.00000			
TDS	0.15409	-0.12603	0.99859	0.99933	1.00000		
Cl	-0.09895	-0.04355	0.58292	0.60963	0.61285	1.00000	
Alkalinity	0.13214	-0.00795	0.93136	0.93352	0.93379	0.52971	1.00000

EC, Electrical Conductivity; TDS, Total Dissolved Solids.

[a] Unit of measurement is expressed in parts per million (ppm).

Table 5. Chloride-Bicarbonate ratio of groundwater and the level of saltwater intrusion

Site	High Tide				Low Tide			
	Chloride	Alkalinity	Saltwater Intrusion Ratio	Level of Intrusion	Chloride	Alkalinity	Saltwater Intrusion Ratio	Level of Intrusion
S1	64.43	418.32	0.15	Normal	60.34	462.80	0.13	Normal
S2	20.17	374.04	0.05	Normal	20.66	368.85	0.06	Normal
S3	10.16	115.20	0.09	Normal	10.19	100.05	0.10	Normal
S4	16.07	114.48	0.14	Normal	16.93	110.42	0.15	Normal
S5	42.79	391.68	0.11	Normal	57.55	431.60	0.13	Normal
S6	49.84	295.22	0.17	Normal	36.50	380.99	0.10	Normal
S7	90.79	178.44	0.51	Low	66.09	380.64	0.17	Normal
S8	51.48	309.96	0.17	Normal	19.73	319.28	0.06	Normal
S9	40.00	277.56	0.14	Normal	35.18	380.64	0.09	Normal
S10	34.43	361.80	0.10	Normal	35.68	385.61	0.09	Normal
S11	29.67	303.84	0.10	Normal	45.38	365.35	0.12	Normal
S12	30.42	624.60	0.05	Normal	36.17	634.06	0.06	Normal
S13	22.52	280.15	0.08	Normal	24.99	284.76	0.09	Normal
S14	32.06	391.32	0.08	Normal	30.09	356.76	0.08	Normal
S15	28.94	633.24	0.05	Normal	24.99	410.80	0.06	Normal
S16	53.11	402.12	0.13	Normal	33.71	632.23	0.05	Normal
S17	52.45	402.12	0.13	Normal	33.87	265.65	0.13	Normal
S18	28.53	292.24	0.10	Normal	28.61	310.96	0.09	Normal
S19	64.43	412.19	0.16	Normal	31.73	451.41	0.07	Normal
S20	50.17	340.08	0.15	Normal	26.31	397.08	0.07	Normal
S21	38.36	276.99	0.14	Normal	24.50	282.53	0.09	Normal
S22	75.20	150.15	0.50	Low	39.62	356.04	0.11	Normal
S23	316.97	591.41	0.54	Low	151.26	594.37	0.25	Normal

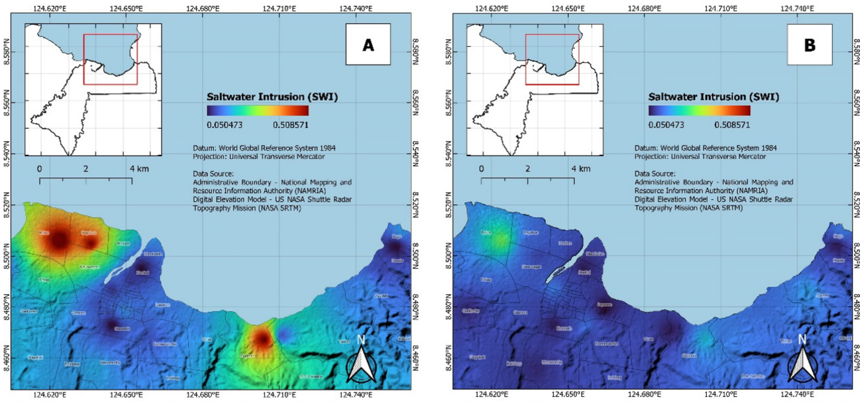

Figure 2. Geographic distribution of saltwater intrusion in Cagayan de Oro during: a.) High tide b.) Low tide

Table 6 statistically shows the factors that affect the occurrence of SWI in Cagayan de Oro based on geochemical analysis. Among the variables measured, only chloride concentration was known to be positively associated with SWI while the rest shows a negative correlation. Multiple linear regression model which was implemented using backward elimination method complemented these results showing that increasing chloride concentration by a factor of 1 may consistently increase SWI by 0.002 in two backward elimination procedure, while alkalinity was found to be negatively correlated with SWI, in which increasing alkalinity by a factor of 1 may decrease SWI (r2 = 0.76) (Table 7 and Table 8).

Similar to the analysis of Yi et al., (2012), results showed that tidal actions and slope characteristics of the landscape may likely ameliorate the amount of seawater in the shallow coastal groundwater of western Cagayan de Oro since these areas, specifically Bulua and Kauswagan has the lowest slope, flatter elevation and closer distance relative to the coast among all sampling wells in the study, making seawater migration easier compared to areas characterized with steep slopes, high elevation, and farther from coastal realms of the city (Figure 2, Figure 3a, Figure 3b, and Table 9).

Table 6. Correlation matrix of saltwater intrusion ratio to other related variables

	SWI Ratio	*pH*	*distance from the coast*	*TDS*	*salinity*	*conductivity*	*Chloride*	*Alkalinity*
SWI Ratio	1.00000							
pH	-0.37669	1.00000						
Distance from the coast [b]	-0.06678	-0.68018	1.00000					
TDS [a]	-0.12555	0.00611	0.36634	1.00000				
Salinity [a]	-0.19053	-0.01447	0.35908	0.78640	1.00000			
Conductivity [a]	-0.19126	-0.01482	0.36264	0.78964	0.99868	1.00000		
Chloride [a]	0.71074	-0.31204	0.05422	-0.10644	-0.08264	-0.08992	1.00000	
Alkalinity [a, c]	-0.19967	0.10274	0.10362	0.13282	0.42428	0.41486	0.41956	1.00000

EC, Electrical Conductivity; TDS, Total Dissolved Solids.

[a] Unit of measurement is expressed in parts per million (ppm).

[b] Unit of measurement is in terms of meters (m). Distance from the coast was estimated using satellite images from Google Earth Pro.

[c] Alkalinity is the sum of HCO_3^- and CO_3^{2-}.

Table 7. Regression analysis result during first backward elimination procedure

	Estimate	Standard Error	T-value	P-value
Intercept	3.80E - 01	4.79E - 01	0.794	0.441629
Chloride	2.06E - 03	4.79E - 04	4.312	0.000844 ***
Alkalinity	-6.73E - 04	1.92E - 04	-3.498	0.003931 **
Distance from the Coast	-5.46E - 06	1.48E - 05	-0.368	0.718568
Elevation	-0.005034	5.64E - 03	-0.893	0.388129
Slope	1.72E - 04	7.58E - 03	0.023	0.982273
pH	-1.62E - 02	7.30E - 02	-0.222	0.828099
EC	2.65E - 03	1.98E - 03	0.573	0.57621
Salinity	2.65E - 03	3.57E - 03	0.742	0.471351
TDS	-3.56E - 03	3.06E - 03	-1.165	0.26512

*** Significant at alpha < 0.0001

** Significant at alpha < 0.001

Table 8. Regression analysis result during second backward elimination procedure

	Estimate	Standard Error	T-value	P-value
Intercept	0.2192276	0.0410999	5.334	3.20e - 05 ***
Chloride	0.0021508	0.0002743	7.841	1.59e - 07 ***
Alkalinity	-0.0004909	0.0001178	-4.166	0.000477 ***

*** Significant at alpha < 0.0001

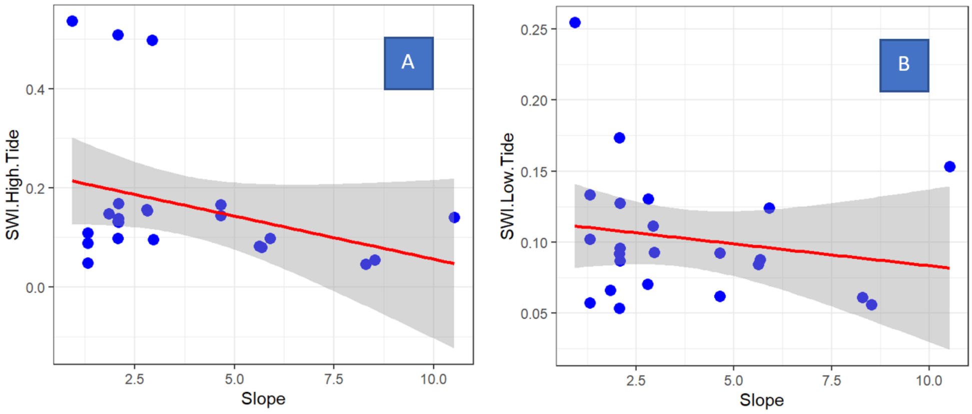

Figure 3. Relationship saltwater intrusion ratio and slope; a.) Observation of SWI during high tide b.) Observation of SWI during low tide

Table 9. Regression analysis between SWI and topographic characteristics of deep wells

	Estimate	Standard Error	T-value	P-value
Intercept	3.22E - 01	8.27E - 02	3.895	0.000974 ***
Slope	-1.75E -02	1.22E - 02	-1.438	0.166711
Distance from the Coast	-1.06E - 05	1.99E - 05	-0.534	0.599497
Elevation	-8.36E - 03	8.72E - 03	-0.959	0.349445

*** Significant at alpha < 0.0001

4. Conclusion

This study presented baseline information concerning the SWI in Cagayan de Oro, accomplished via geochemical analyses. Study showed that deep wells in Cagayan de Oro is dominated by bicarbonate and carbonate, indicating intrinsic characteristics of unconfined groundwater. While the majority of the groundwater sampling points are still considered normal under Na/Cl purview, it is alarming that most western coastal areas exhibited characteristics that are slightly intruded by seawater. Tidal oscillations statistically registered significant differences, showing that salt enrichment is likely ameliorated during high tide events. Inherent topographic characteristics of landscape specifically flat surfaces, proximity to the coast and low elevation were deemed to be negatively correlated with SWI. It is also concluded that elevated SWI in western coast of the city may be induce by excessive water withdrawals as evidenced by increased population influx that happened in recent years. While results still showed favorable empirical evidence about SWI, the exigency of continuous monitoring of the city's groundwater resources is imperative to ensure the sustainability of these finite resources.

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References

Abd-Elaty I, Abd-Elhamid HF, Nezhad MM. Numerical analysis of physical barriers systems efficiency in controlling saltwater intrusion in coastal aquifers. Environmental Science and Pollution Research 2019; 26(35): 35882-25889.

Alfarrah N, Walraevens K. Groundwater overexploitation and seawater intrusion in coastal areas of arid and semi-arid regions. Water 2018; 10(2): 143.

APHA. Standard methods for the examination of water and waste water. 19th ed. Washington, DC. 1995.

Barlow PM, Reichard, EG. Saltwater intrusion in coastal regions of North America. Hydrogeology Journal 2010; 18(1): 247-260.

Davis SN, De Wiest RJ. Hydrogeology. Wiley, New York, USA. 1966.

Ebrahimi M, Kazemi H, Ehtashemi M, Rockaway TD. Assessment of groundwater quantity and quality and saltwater intrusion in the Damghan basin, Iran. Geochemistry 2016; 76(2): 227-241.

EL Hamidi MJ, Larabi A, Faouzi, M. Numerical Modeling of Saltwater Intrusion in the Rmel-Oulad Ogbane Coastal Aquifer (Larache, Morocco) in the Climate Change and Sea-Level Rise Context (2040). Water 2021; 13(16): 2167.

Krishnakumar S, Chandrasekar N, Seralathan P, Godson PS, Magesh NS. Hydrogeochemical study of shallow carbonate aquifers, Rameswaram Island, India. Environmental monitoring and assessment 2012; 184(7): 4127-4138.

Ng RA, Ventura NS, Guerra N, Mercado NB, De Leon M. Investigation of the State and Condition of Saltwater Intrusion in Cebu City Aquifers in the Philippines. Proceedings of the ISER 131st International Conference 2018.

Ngilangil LE, Vilar DA, Andrada JC, Lucena JJ. Geographic Mapping of Tube Wells and Assessment of Saltwater Intrusion in the Coastal Areas of La Union. Chemical Engineering Transactions 2018; 63: 55-60.

Palanca-Tan R. Designing a Raw Water Fee Scheme for Groundwater Extraction in Cagayan de Oro, Philippines. 2011.

Panjaitan D, Tarigan J, Rauf A, Nababan ES. Determining Sea water intrusion in shallow aquifer using Chloride Bicarbonate Ratio Method. In IOP Conference Series: Earth and Environmental Science 2018; 205(1): 012029.

Prusty P, Farooq SH. Seawater intrusion in the coastal aquifers of India-A review. HydroResearch 2020; 3: 61-74.

Racadio CDT, Castañeda SS, Cariño FA, Mendoza ND. Isotopic data for inferring groundwater dynamics in Cagayan de Oro city, Philippines. Philippine Journal of Science 2020; 149(1): 188-199.

Safi A, Rachid G, El-Fadel M, Doummar J, Abou Najm M, Alameddine I. Synergy of climate change and local pressures on saltwater intrusion in coastal urban areas: Effective adaptation for policy planning. Water International 2018; 43(2): 145-164.

Sarath Prasanth SV, Magesh NS, Jitheshlal KV, Chandrasekar N, Gangadhar KJA. Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. Applied Water Science 2012; 2(3): 165-175.

Yi LIU, Shang SH, Mao XM. Tidal effects on groundwater dynamics in coastal aquifer under different beach slopes. Journal of Hydrodynamics 2012; 24(1): 97-106.

Zhou X, Shen Y, Zhang H, Song C, Li J, Liu Y. Hydrochemistry of the natural low pH groundwater in the coastal aquifers near Beihai, China. Journal of Ocean University of China 2015; 14(3): 475-483.