Determining sea water intrusion in shallow aquifer using Chloride Bicarbonate Ratio Method

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Abstract. Increasing usage of ground water tends to cause sea water intrusion. Sea water intrusion often happens in coastal areas. This study was conducted to determine the spread, levels of intrusion and factors that affect sea water intrusion in the research area. The sampling technique was carried out using interval random sampling, where 30 samples were taken with a distance of 2 km each, and then chemical analysis was carried out including the parameters of Cl^-, HCO_3^-, $CO_3^=$, and electrical conductivity (EC). The method used to determine the level of seawater intrusion was the method of Chloride Bicarbonate Ratio and then the types of water were classified based on chloride content and electrical conductivity. The determination of the distribution of seawater intrusion was done by mapping analysis using the ArcGis application program. To determine the factors that affected sea water intrusion, multivariate regression analysis with the "backward elimination" method was used. The results showed that on several sample points the shallow aquifer had been intruded by sea water with a ratio of 1.02 to 102.16 which were included in the category of intrusion of slightly to high. Chloride concentrations ranged from 2 mg/L to 31,160 mg/L and were classified as fresh water to salt water. Electrical conductivity ranged from 186 µmhos/cm to 26,400 µmhos/cm and generally above 200 µmhos/cm which meant that the sea water had been disturbed. Factors that significantly affected sea water intrusion were water usage debit and aquifer permeability with an adjusted coefficient R^2 of 0.797.

Keywords: groundwater, aquifer, sea water intrusion

1. Introduction

Water is very important to the survival of living things. All living things on earth -plants, animals and humans- need water. One alternative source of water is ground water. Ground water can be used easily and economically, and it is exploited by drilling or digging.

Lately, groundwater use has increased in line with the increase in population. The groundwater is used for residential, industrial and agricultural needs. The distribution of ground water resources is limited and spread unevenly in time and space, due to differences in geography, climate and land use.

The continuous exploitation of groundwater, without taking into account the production power of an aquifer, decreases the surface of the groundwater. The continuous exploitation of groundwater causes in the intrusion of sea water into groundwater aquifers in the land, which is called sea water intrusion.

Sea water intrusion is a problem in coastal areas. Figure 1 illustrates the condition of a coastal system. An ideal hydrogeological cross section is indicated by a freshwater aquifer system that is hydraulically connected to sea water. In normal condition there is a balanced hydraulic slope (interface), with the direction from land to sea (Figure 1a). With a decrease in the flow of fresh water that leads to the sea, the interface moves into the land and produces sea water intrusion into the freshwater aquifer on land, as shown in Figure 1b. Conversely an increase in the flow of fresh water pushes the interface line towards the sea [1].

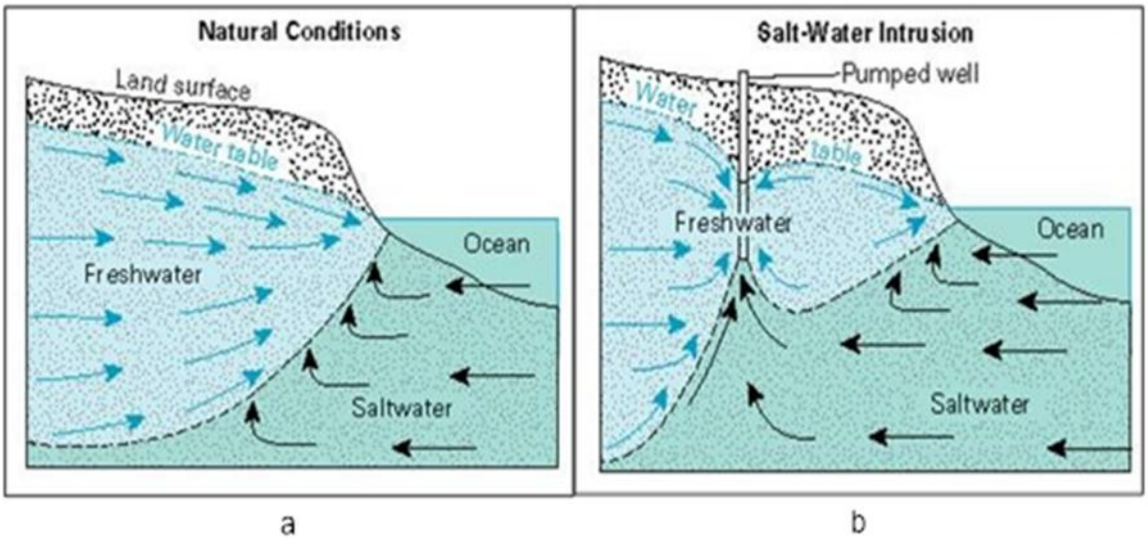

Figure 1. The condition of a groundwater aquifer system a. Natural condition b. Intrusion of sea water [1].

Excessive groundwater extraction, especially in coastal areas, which results in seawater intrusion is a problem that occurs throughout the world [2-12]. Determination of seawater intrusion has been carried out using various methods and techniques, including geoelectric resistivity techniques [13-15], methods with analytical models [16-19], and numerical simulation model that is widely used [20-28]. This study used the Chlorida Bicarbonate Ratio method, a method that used an ion ratio as a basis to determine the presence of sea water intrusion. Chloride is the dominant ion found in seawater and is trace in ground water, while bicarbonate is the dominant ion in groundwater and is few in sea water. The ratio value between chloride level and the amount of carbonate and bicarbonate is a determinant of ground water classification in determining the level of sea water intrusion [29].

Today, and presumely in the future, the balance of ground water will be increasingly disrupted, in addition to the increasing need for ground water along with the increase in population, also due to the conversion of land into settlements, infrastructure and industry. This will reduce the water catchment area so that the amount of water that enters the soil to replace the coming out groundwater becomes less. On the other hand, the level of forest encroachment in the upstream area as a rainfall catchment area will eventually reduce groundwater availability. The problem of sea water intrusion is also affected by the morphological and geological conditions of the ground water aquifer. This study aimed to find out: the distribution, level of intrusion and factors that affect seawater intrusion in the research area.

2. Research Methods

This research was carried out in the coastal area of Belawan, Medan Belawan District and its surroundings, which was geographically located between Medan and the Malacca Strait. Topography of Medan Belawan tended to be sloping and was at an altitude of 3 meters above sea level. This location was selected because this location was close to the coastline and was directly adjacent to the Malacca Strait, making it vulnerable to sea water intrusion problems. Besides, the level of development of Belawan area and its population growth were quite high, which consequently would utilize a big amount of water, especially ground water. This situation would cumulatively increase the risk of sea water intrusion problems. The location and scheme of the research can be seen in Figure 2.

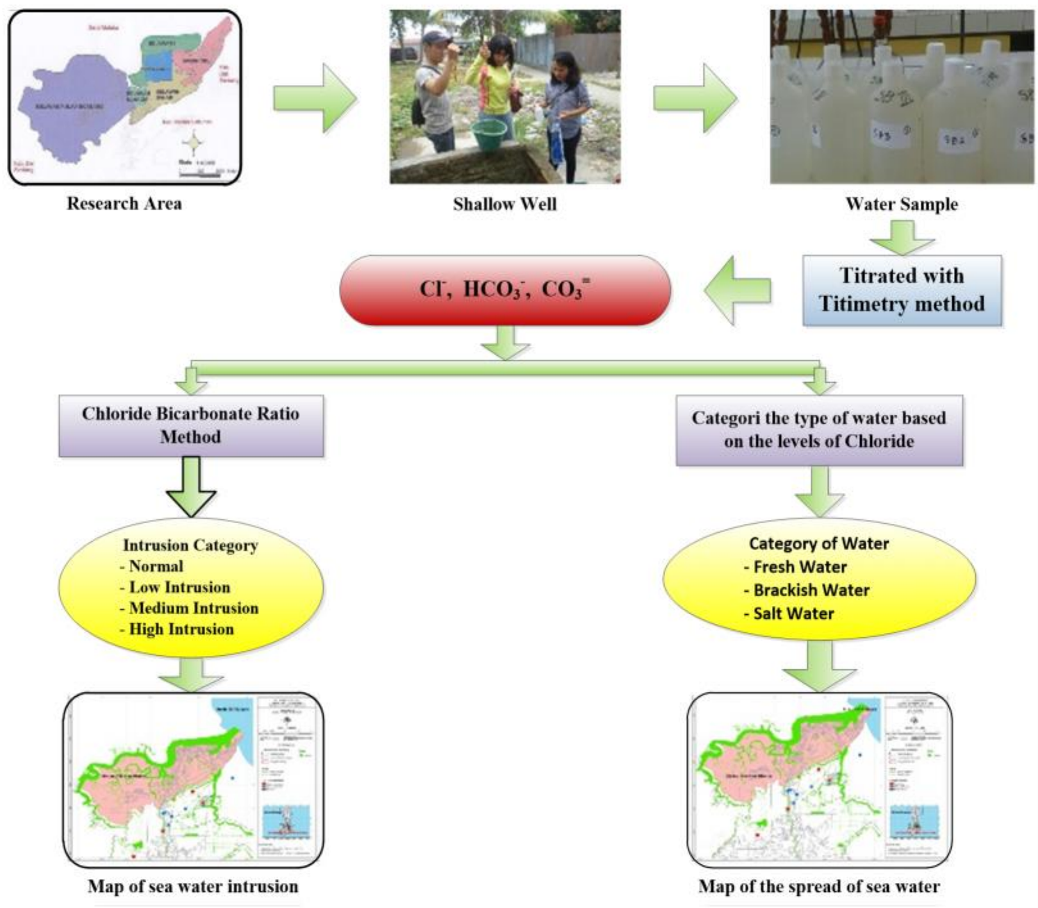

Figure 2. Flowchart of research

From this location 30 water samples were taken from shallow wells at random sampling intervals, with a distance of 2 km each, starting from the coastline to the land. Then a chemical analysis was carried out on the well water samples which included the parameters of Chlorida (Cl^-), Carbonate (HCO_3) and Bicarbonate ($CO_3^=$) using the Titimetry method, and electrical conductivity (EC) was measured using a conductometer. The method used to determine the level of seawater intrusion was the Chloride Bicarbonate Ratio method, that compared Cl^- concentration with the total concentration of $HCO3^-$ and $CO3^=$ [29].

The ratio value between chloride levels and the total of carbonate and bicarbonate levels was a determinant of groundwater classification in determining the level of sea water intrusion. This ratio was divided into six categories: normal or no intrusion (<0.5); low (0.5-1.3); moderate (1.3-2.8); rather high (2.8-6.6); high (6.6-15.5); and sea water (> 15.5). Meanwhile, water types based on chloride concentration consisted of three categories: fresh water (0-200); brackish water (200-600); and salt water (> 600) [30]. Furthermore, based on the water classification, a mapping analysis on the sea water distribution and its intrusion was carried out using the ArcGis application program. To determine the factors that affected seawater intrusion, a multivariate regression analysis with backward elimination method was used. In this case the variables that were predicted would affect seawater intrusion were used as independent variables these included: elevation (the height of the research subject from sea level), depth of well, well distance from the coastline, discharge of water, rock type, porosity and permeability of aquifers and land cover. The dependent variable was chloride as an indicator of sea water intrusion.

3. Results and Discussion

The results of the analysis in Table 1. showed that based on the Chloride Bicarbonate Ratio method there were several locations that had been intruded by seawater. These were locations that showed a ratio value higher than 0.5. The location with SG13 and SG18 sample codes were categorized as low intrusion; samples of SG10, SG14, SG17, SG19 and SG22 were medium intrusion; and samples of SG11, SG23, SG24, SG25, SG26 and SG27 were included in high intrusion category. The lowest ratio value of 1.02 was found at SG13 and the highest was 102.16 at SG26. This meant that there was an infiltration of sea water into freshwater aquifers on land. This was also supported by the results of Chloride analysis where the Chloride concentrations were more than 200 mg/L and electrical conductivity that ranged from 186 µmhos/cm to 26.400 µmhos/cm at several sample points. In general, electrical conductivity were above 200 µmhos/cm which meant that well water had been intruded by sea water.

Figure 3. showed that these intruded sample points tended to be around the coast, except SG13 and SG14, and formed the direction according to groundwater flow, so that it was expected that the high chloride content at those points were due to the influence of sea water ingression. Table 2. showed the result of measurements of independent variables of the shallow wells. The sample points in this table was at elevations that varied greatly from 2 meters to 7 meters above sea level, and most of these polluted points were at 3 meters elevation. The depth of these polluted wells also varied greatly from 1 meter to 35 meters, and generally was at a depth of 20 meters. This highly varied depth meant that the intrusion of sea water into wells on land was not a function of depth but as a function of pressure. The condition of water flow in the soil was analogous to the flow of water in a related vessel, where water would flow to a room with a lower pressure. Excessive exploitation of ground water reduced water pressure in groundwater aquifers so that sea water with higher pressure broke into the aquifers.

In addition, these polluted locations consisted of aquifers with sand and gravel rock types that had high permeability, with a permeability value of 41 m/day for sand and 4100 m/day for gravel [1]. Another reason was the rate of water usage; it was estimated that the population of Belawan was around 512.000 people with an average water requirement of 200 liters per day, so that they took 102.400 m^3/day or 37.376.000 m^3/year of clean water. The need for water was quite large, which was not comparable with the average amount of rainfall which was around 2120 mm/year. It was this water withdrawal that mostly played the role in lowering the groundwater surface. On the other hand, there was a factor of the conversion of land functions into settlements, industries and infrastructure facilities that reduced water absorption into the soil. Together, all these factors simultaneously affected the sea water intrusion.

Table 1. Classification of groundwater and the level of intrusion

No	Code	Location	EC (mmhos/cm)	Clorida (Cl) (mg/L)	Carbonat (HCO_3^-) (mg/L)	Bicarbonat ($CO_3^=$) (mg/L)	Ratio $\frac{Cl}{(HCO_3^- + CO_3^=)}$	The Level of Intrusion	Category of Water
1	SG1	Medan Labuhan	1354	22.27	38.45	86.34	0.18	Normal	Fresh Water
2	SG2	Medan Labuhan	1783	25.25	41.27	74.28	0.22	Normal	Fresh Water
3	SG3	Medan Labuhan	1682	28.44	39.36	81.63	0.24	Normal	Fresh Water
4	SG4	Medan Labuhan	1724	23.82	37.82	79.22	0.20	Normal	Fresh Water
5	SG5	Medan Labuhan	1587	29.54	40.67	86.36	0.23	Normal	Fresh Water
6	SG6	Medan Labuhan	377	18.85	49.50	381.30	0.04	Normal	Fresh Water
7	SG7	Medan Labuhan	368	71.47	234.30	707.60	0.08	Normal	Fresh Water
8	SG8	Labuhan Deli	402	31.00	15.40	305.00	0.10	Normal	Fresh Water
9	SG9	Labuhan Deli	370	32.00	13.20	165.00	0.18	Normal	Fresh Water
10	SG10	Medan Marelan	3740	1490.00	26.40	387.00	3.60	Middle Intrusion	Salt Water
11	SG11	Medan Labuhan	26400	10200.00	24.20	175.00	51.20	High Intrusion	Salt Water
12	SG12	Medan Deli	453	40.00	198.00	288.00	0.08	Normal	Fresh Water
13	SG13	Medan Deli	674	320.00	13.20	302.00	1.02	Low Intrusion	Brackish Water
14	SG14	Medan Deli	686	1500.00	33.00	465.00	3.01	Middle Intrusion	Salt Water
15	SG15	Medan Labuhan	1252	340.00	66.00	1007.00	0.32	Normal	Brackish Water
16	SG16	Medan Labuhan	883	102.00	22.00	511.00	0.19	Normal	Fresh Water
17	SG17	Labuhan Deli	753	107.00	4.40	24.40	3.72	Middle Intrusion	Fresh Water
18	SG18	Medan Labuhan	770	42.00	6.60	33.50	1.05	Low Intrusion	Fresh Water
19	SG19	Bagan Deli	2367	1052.00	66.34	182.30	4.23	Middle Intrusion	Salt Water
20	SG20	Medan Labuhan	379	48.00	35.20	125.00	0.30	Normal	Fresh Water
21	SG21	Medan Labuhan	513	76.00	7.00	247.00	0.30	Normal	Fresh Water
22	SG22	Medan Labuhan	884	83.00	8.80	24.40	2.50	Middle Intrusion	Fresh Water
23	SG23	Bagan Deli	1640	9167.00	20.00	247.00	34.33	High Intrusion	Salt Water
24	SG24	Bagan Deli	1092	294.00	4.40	21.35	11.42	High Intrusion	Brackish Water
25	SG25	Medan Labuhan	1947	13719.00	38.00	466.00	27.22	High Intrusion	Salt Water
26	SG26	Medan Labuhan	1962	31160.00	31.00	274.00	102.16	High Intrusion	Salt Water
27	SG27	Medan Labuhan	1715	8656.00	20.00	277.00	29.14	High Intrusion	Salt Water
28	SG28	Medan Labuhan	262	2.00	22.00	671.00	0.00	Normal	Fresh Water
29	SG29	Medan Sicanang	186	3.00	10.00	330.00	0.01	Normal	Fresh Water
30	SG30	Medan Belawan	218	3.00	60.00	314.00	0.01	Normal	Fresh Water

The results of chloride analysis for these shallow aquifers varied widely between 2 mg/L to 31.160 mg/L. Table 1. showed that water classification based on chloride concentration generally was able to be categorized as fresh water. However, there were several wells with high chloride concentration, those were samples with codes: SG10, SG11, SG14, SG23, SG25, SG26 and SG27 that were categorized as saltwater, and samples with codes SG13, SG15 and SG24 that were included into the brackish water category. This meant that the research area had been contaminated with sea water. Sea water distribution and its intrusion was able to be seen in Figure 3.

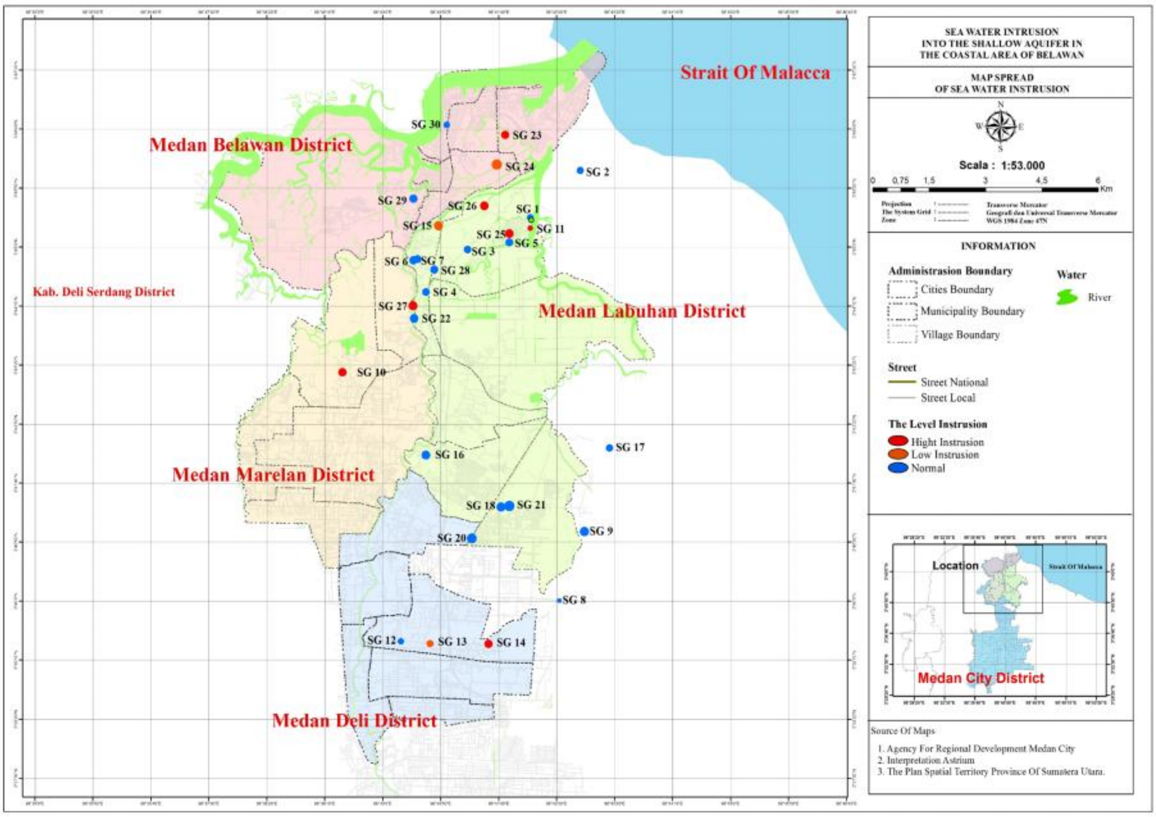

Figure 3. Map of the spread of sea water intrusion

Figure 3. showed the spread of sea water intrusion and the spread of sea water at the research area. The image showed that sea water and its intrusion were scattered in almost all research locations. This intrusion was suspected to be affected by several factors: the debit of water usage, the elevation or altitude above sea level, well depth, distance from the coast line and also the geological characteristics of the aquifer which included rock type, porosity and permeability. According to [1], permeability was a measure of easiness of water to flow through a porous medium. The amount of groundwater that can be obtained in an area depended on the characteristics of aquifers in the area as well as the extent and frequency of the particles. The capacity of a formation to hold water was measured by porosity, which was the ratio between the volume of pores to the total volume of the formation. Pores had a varying size, from those in the form of submicroscopic cracks in clay and shale, to those in the form of caves and tunnels in limestone and lava. It should be noted that materials with high porosity were not necessarily good aquifers. Mississippi River sediments often had a porosity of 80 to 90 percent but their permeability was so low that only a small amount of water was able to be found in the wells [31]. In addition, land cover that acted as a water barrier, also had an indirect effect on sea water intrusion.

Table 2. Data of independent variables on shallow wells

No	Code	Location	Elevation (m)	Depth (m)	Distance (m)	Debit (m3/month)	Aquifer	Porosity	Permeability (m/day)	Land cover
1	SG1	Medan Labuhan	1	20	47	38	Clay	45	0.0004	Field
2	SG2	Medan Labuhan	1	10	100	38	Sandy clay	35	41	Field
3	SG3	Medan Labuhan	3	10	2630	45	Sandy clay	35	41	Field
4	SG4	Medan Labuhan	5	2	4210	53	Clay	45	0.0004	Settlement
5	SG5	Medan Labuhan	3	36	1840	53	Sandy clay	35	41	Settlement
6	SG6	Medan Labuhan	6	3	3950	30	Sandy clay	35	41	Settlement
7	SG7	Medan Labuhan	4	3	3850	60	Sandy clay	35	41	Settlement
8	SG8	Labuhan Deli	2	12	11900	38	Sand	35	41	Settlement
9	SG9	Labuhan Deli	2	10	9910	53	Sand	35	41	Settlement
10	SG10	Medan Marelan	3	3	7000	68	Sandy clay	35	41	Field
11	SG11	Medan Labuhan	2	1	58	150	Clay	45	0.0004	Field
12	SG12	Medan Deli	7	6	12300	53	Clay	45	0.0004	Field
13	SG13	Medan Deli	4	18	12100	68	Sand	35	41	Settlement
14	SG14	Medan Deli	6	3	11950	120	Clay	45	0.0004	Field
15	SG15	Medan Labuhan	3	3	2950	60	Sandy clay	35	41	Settlement
16	SG16	Medan Labuhan	3	3	7600	60	Clay	35	0.0004	Settlement
17	SG17	Labuhan Deli	3	2	7680	53	Clay	45	0.0004	Field
18	SG18	Medan Labuhan	6	21	8400	38	Sand	35	41	Settlement
19	SG19	Bagan Deli	3	30	990	68	Sandy clay	35	41	Settlement
20	SG20	Medan Labuhan	3	3	9250	45	Clay	45	0.0004	Settlement
21	SG21	Medan Labuhan	4	15	8350	38	Sand	35	41	Field
22	SG22	Medan Labuhan	7	3	4750	45	Sandy clay	45	41	Settlement
23	SG23	Bagan Deli	3	36	1200	120	Sandy clay	35	41	Settlement
24	SG24	Bagan Deli	3	36	1040	68	Sandy clay	35	41	Settlement
25	SG25	Medan Labuhan	4	20	1550	158	Gravel	25	4100	Field
26	SG26	Medan Labuhan	4	20	1480	180	Gravel	25	4100	Settlement
27	SG27	Medan Labuhan	2	21	4638	75	Gravel	25	4100	Field
28	SG28	Medan Labuhan	2	21	3590	38	Gravel	25	4100	Settlement
29	SG29	Medan Sicanang	5	21	3290	30	Clay	45	0.0004	Plantation
30	SG30	Medan Belawan	4	20	2670	30	Clay	45	0.0004	Plantation

From the results of multivariate regression analysis with the backward elimination method in Table 3**.** the value of the adjusted determination coefficient R^2 of 0.797 was obtained. This meant that 79.7 percent of the chlorida variable was able to be explained by the variables of water debit and permeability of the aquifer

Table 3. Model Summary of multivariat regression analysis with backward elimination method

Model	R	R Square	Adjusted R Square	F_t	Sig
1	.916[a]	.839	.778	13.668	0.000
2	.916[b]	.838	.787	16.282	0.000
3	.915[c]	.837	.794	19.620	0.000
4	.911[d]	.830	.794	23.410	0.000
5	.908[e]	.824	.796	29.343	0.000
6	.905[f]	.819	.798	39.197	0.000
7	.900[g]	.811	.797	57.820	0.000

1. Predictor: (Constant), Elevation, Debit, Land Cover, Depth, Porosity, Distance, Aquifer, Permeability
2. Predictor: (Constant), Elevation, Debit, Land Cover, Depth, Porosity, Distance, Permeability
3. Predictor: (Constant), Debit, Land Cover, Depth, Porosity, Distance, Permeability
4. Predictor: (Constant), Debit, Land Cover, Porosity, Distance, Permeability
5. Predictor: (Constant), Debit, Land Cover, Distance, Permeability
6. Predictor: (Constant), Debit, Distance, Permeability
7. Predictor: (Constant), Debit, Permeability

Table 3. also showed the results of multivariate regression analysis with the backward elimination method and gave 7 models, from a to g. The most influential model was the model that had the highest F test (Ft) value with a significant value below 0.05, which was found in the Model g. From the covariance analysis test, the Ft value was 57.820 and the significance value was 0.000, which meant that both the water debit and permeability factors significantly affected the chloride concentration. In another words, this regression model was able to be used to predict the value of chloride.

Belawan region is an area that was quite developed, which indicated by high economic activity, development and population. As a consequence, the area would require considerable water as a source of life. Groundwater exploitation was an alternative in providing water needs, because it was able to be obtained easily and economically. It can be predicted that the exploitation of groundwater had exceeded the production capacity of aquifers, so that the surface water level of the groundwater was reduced. In other words, groundwater pressure became lower than sea water pressure that made the ground water to be penetrated by sea water.

Seawater intrusion that occurred in this research area was also affected by aquatic lithology conditions consisting of gravel, sand and clay, where the intruded points were dominated by high permeability condition which passed the water relatively easy, thus facilitating seawater intrusion. This condition was supported by land use factors in this area which were predominantly residential and industrial, which affected the infiltration of water into the groundwater aquifer. In addition, in order to support the local economy, many people opened ponds along the coast that cumulatively increased the risk of sea water intrusion.

4. Conclusion

Based on these studies it was concluded that chloride concentrations of the shallow aquifers ranged from 2 mg/L to 31.160 mg/L and were included in the category of fresh water to salt water. The level of intrusion based on the method of Chloride Bicarbonate Ratio ranged from 1.02 to 102.16 with the low intrusion category to high intrusion. Electrical conductivity ranging from 186 μmhos/cm to 26.400 μmhos/cm. The occurrence of seawater intrusion in the research area was affected by the factors of water debit and aquifer permeability with the adjusted coefficient of determination R^2 of 0.797.

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Acknowledgements
The authors would like to extend his gratitude to Indonesian Government for its financial support, Catholic University of Santo Thomas Sumatera Utara for its support during the research, and also to University of Sumatera Utara for allowing the using of facilities to conduct the research.