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 \( \text{Cl}^-, \text{HCO}_3^-, \text{CO}_3^2-, \) 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 mhos/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].](image)

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 presumably 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.

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\(_3\)^2-) 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 HCO\(_3\) and CO\(_3\)^2- [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, 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 mhos/cm to 26.400 mhos/cm at several sample points. In general, electrical conductivity were above 200 mhos/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 ingress. 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 m³/day or 37,376.000 m³/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) | Chloride (Cl) (mg/L) | Carbonat (HCO₃⁻) (mg/L) | Bicarbonat (CO₃²⁻) (mg/L) | Ratio Cl | 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               | 66.00                    | 1007.00                   | 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       |                     | Field      |
| 3  | SG3  | Medan Labuhan   | 3             | 10        | 2630         | 45                | Sandy clay | 35       |                     | 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       |                     | Settlement |
| 6  | SG6  | Medan Labuhan   | 6             | 3         | 3950         | 30                | Sandy clay | 35       |                     | Settlement |
| 7  | SG7  | Medan Labuhan   | 4             | 3         | 3850         | 60                | Sandy clay | 35       |                     | Settlement |
| 8  | SG8  | Labuhan Deli    | 2             | 12        | 11900        | 38                | Sand    | 35        |                     | Settlement |
| 9  | SG9  | Labuhan Deli    | 2             | 10        | 9910         | 53                | Sand    | 35        |                     | Settlement |
| 10 | SG10 | Medan Marelan    | 3             | 3         | 7000         | 68                | Sandy clay | 35       |                     | 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        |                     | 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       |                     | 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        |                     | Settlement |
| 19 | SG19 | Bagan Deli      | 3             | 30        | 990          | 68                | Sandy clay | 35       |                     | Settlement |
| 20 | SG20 | Medan Labuhan   | 3             | 3         | 9250         | 45                | Clay    | 45        | 0.0004              | Settlement |
| 21 | SG21 | Medan Labuhan   | 4             | 15        | 8350         | 38                | Sand    | 35        |                     | Field      |
| 22 | SG22 | Medan Labuhan   | 7             | 3         | 4750         | 45                | Sandy clay | 45       |                     | Settlement |
| 23 | SG23 | Bagan Deli      | 3             | 36        | 1200         | 120               | Sandy clay | 35       |                     | Settlement |
| 24 | SG24 | Bagan Deli      | 3             | 36        | 1040         | 68                | Sandy clay | 35       |                     | 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 multivariate regression analysis with backward elimination method**

| Model | R     | R Square | Adjusted R Square | $F_t$ | Sig  |
|-------|-------|----------|-------------------|-------|------|
| 1     | 0.916 | 0.839    | 0.778             | 13.668| 0.000|
| 2     | 0.916 | 0.838    | 0.787             | 16.282| 0.000|
| 3     | 0.915 | 0.837    | 0.794             | 19.620| 0.000|
| 4     | 0.911 | 0.830    | 0.794             | 23.410| 0.000|
| 5     | 0.908 | 0.824    | 0.796             | 29.343| 0.000|
| 6     | 0.905 | 0.819    | 0.798             | 39.197| 0.000|
| 7     | 0.900 | 0.811    | 0.797             | 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 $F_t$ value with a significant value below 0.05, which was found in the Model g. From the covariance analysis test, the $F_t$ 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 mhos/cm to 26.400 mhos/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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