Geophysical and Geochemical Approach for Seawater Intrusion Assessment in the Belawan Coast and the Medan Industrial Area, North Sumatera Utara, Indonesia

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Abstract. The uncontrolled underground water exploitation and inadequate domestic and industrial wastewater control systems have contributed significantly to groundwater degradation. The groundwater degradation potentially initiates the seawater intrusion especially on the coastal area. The present study aims to analyze the seawater intrusion using geophysical and geochemical approach in the coastal area of Belawan and Medan Industrial Area which close to the coastal area. 15 borehole water samples collected were analyzed to determine anions, cations concentrations, and facies. The results showed that the lithostratigraphy of the study area consisted of alluvial in form of watery gravel and clay layers. The investigation of the groundwater using the geoelectric method showed that the resistivity values for track 1 (GL-1) and track (GL-02) are 129Ω to 371Ω. These values are interpreted as layers of sand that have experienced seawater intrusion at a depth of 40-60 meters. Furthermore, the water quality tests at the point of wells 1 and 2 on the chloride parameter, where the highest chloride concentration with values of 205.8 mg/l and 203.2 mg/l, was polluted. The result proved that the seawater intrusion has stimulated the groundwater in the coastal area of Belawan and Medan Industrial Area, Indonesia.

1 Introduction

The high level of uncontrolled groundwater exploitation in developing countries in big and small cities has increased drawdowns and deteriorated water quality. Similarly, inadequate domestic and industrial wastewater control systems have contributed significantly to groundwater degradation [1]. Water plays a role in human life, specifically in daily needs [2]. The more people and activities in the coastal area, the higher the use of groundwater increases excessively [3]. The increase in groundwater pollution in coastal plains such as Acquedolci is generally represented by salt water. Over-pumping groundwater, affecting geological factors such as grain size, can be due to overland migration from the freshwater-salt interface called seawater intrusion. This occurs due to the diversion of previously discharged fresh water from coastal aquifers [4]. Therefore, intense anthropic activity affects the coastal hydrological system, which causes groundwater contamination by seawater intrusion. This incidence and problem are noticeably increasing in many coastal and urban areas [5]. Continuous exploitation of aquifers can be observed frequently, which confirms and becomes a concern to the scientific community, as demonstrated by various investigations into groundwater contamination [6].

Geochemical methods based on variations in salinity, cations have been used to detect the seawater intrusion with the additional approach using geophysical to provide a comprehensive picture of the phenomenon [6-8].

Groundwater resources for industrial areas often lead to conflicts of interest. This causes competition in the water use between various users, land conversion, unclear water use rights, weak coordination between stakeholders, and weaknesses in conservation-based water resource management policies [9,10]. Since resistivity is sensitive to fluids and conductive minerals, the general geological conditions of the Belawan area were explained by [11]. It was reported that the coastal alluvial plains are located along the coastline bordering the sea with lithological properties in form of sand and clay, which is the previous rock-crushing material, with a relatively flat topography ranging from 5-10%.

In the present study, the Geoelectric-Schlumberger method (Vertical Electrical Sounding/VES) was used to detect rock layers in an aquifer, where the resistivity is sensitive to fluids and conductive minerals [12], and the groundwater quality and contamination risk was examined using the geochemical method [13]. The electrical conductivity geophysical method (Electrical Conductance) and the geochemical approach through [14,15, 16] have been integrated and successfully used to identify and limit water intrusion in the sea near the surrounding Belawan coastline. The results showed the indications of groundwater contamination, where layers...
I and II comprise sand that has experienced seawater intrusion. The water quality tests reinforce these results carried out on hydrochemical data parameters at the point of wells 1 and 2. The highest chloride (Cl) concentration was obtained with values of 205.8 mg/l and 203.2 mg/l in both wells experiencing pollution [17]. This will provide direction for policymakers in intensifying efforts to develop the environmental industries [18].

2 Materials and Methods

2.1 The studies area location

The study area for geoelectrical and hydro-chemical measurements of groundwater sampling in deep wells are in the residential, shopping, and industrial areas, namely in Medan Belawan and Medan Labuhan Districts, North Sumatra Province, as shown in Fig. 1.

![Fig. 1. Groundwater Sampling Points Map in Belawan and Medan Industrial Area](image)

2.2 Geoelectrical Data Acquisition

The electrical geophysical prospecting method aims to determine the physical distribution of the parameters that are characteristic of the soil layer (resistivity). This is based on the very large number of apparent resistivity measurements from the ground surface. The multi-electrode resistivity survey is a combination of profiling and sounding techniques involving a fixed number of electrodes with inter-electrodes at a particular distance. Generally, a subsurface stratigraphy of measurement principles is generated using two pairs of technical electrodes, namely a current and potential electrode connected to a resistivity meter. Geoelectric section is a rapid method for detecting groundwater, which functions to detect rock layers below the soil surface that contain water (aquifers). Meanwhile, the vertical geoelectric survey (VES) is intended to analyze aquifer characteristics and estimate groundwater content [19-21]. The results of this survey are expected to be used as a guide in groundwater drilling [22].

2.3 Groundwater Sampling and Analysis

The hydrochemical facies is one of the methods used to interpret flow patterns and the origin of groundwater chemistry [23]. This analysis is very useful in identifying hydrogeochemical processes in each groundwater zone characterized by the content of dissolved ions. Based on this study, 15 samples of groundwater were taken from deep wells sourced from industrial, residential, and office activities. The samples were analyzed for all major ions following the standard method [24]. A total of 1 liter of groundwater was collected in plastic bottles, which were previously cleaned twice with distilled water. The elements analyzed include anions and cations such as Calcium (Ca²⁺), Sodium (Na⁺), Magnesium (Mg²⁺), Potassium (K⁺), Chloride (Cl⁻), Bicarbonate (HCO₃⁻), and Sulfate (SO₄²⁻). These elements were analyzed using the diagram analysis method of Trilinear Piper (1944), Stiff diagram (1951), and Durov diagram (1948) for the effective evolution of groundwater chemistry.

3 Results and Discussions

3.1 Correlation of Geoelectrical Data

From the groundwater sampling points map, there were 4 tracks used in the study which were the Bagan Belawan (T1), Sicanang Area (T2), Titi Papan (T3), and Medan Industrial Estate (Kawasan Industri Medan) (T4). The samples were taken with a total track length varying from 250 to 300 meters and the targeted depth were approximately 40 – 60 meters. The survey result was visualized using Res2DIN software. The detail tracking in the studied area are shown below.

3.1.1 .T1/Track 1,Bagan Deli

Track 1 is classified into 3 ranges of resistivity values, for 44Ω-128Ω represented by a deep blue graded to light blue in form of a layer of sand experiencing seawater intrusion. Hydrochemical data support this at wells 1 and 2, where the highest chloride concentration of 205.8 mg/l and 203.2 mg/l were found polluted For the specific value of 129Ω-371Ω, containing alluvial and watery gravel. Meanwhile, 371Ω-1.836Ω is a layer of clay as shown in Fig. 2 with the detail of lithology interpretation shown in Fig. 3.

![Fig. 2. Sub-surface resistivity value map of Track 1 Bagan Belawan](image)
3.1.2 T2/Track 2. Sicanang Sosial

Track 2 consists of 3 ranges of resistivity values, where 0Ω - 4Ω represented by a deep blue graded to light green is a layer of sand that has experienced seawater intrusion. The 5Ω - 60Ω indicated by light green graded to dark red is sandy gravel, and 61Ω - 218Ω represented by dark red grading to dark purple is clay layers with depths ranging from 40-60 meters. Meanwhile, the results of the GL-02 processing are shown in Fig. 4 with the detail of lithology interpretation shown in Fig. 5.

3.1.3 T3/Track 3, Titi Papan

Track 3 consists of 3 ranges of resistivity values, where 0Ω - 4Ω represented by a deep blue graded to light green is a layer of sand that has experienced seawater intrusion. The 5Ω - 60Ω indicated by light green graded to dark red is sandy gravel, and 61Ω - 218Ω represented by dark red grading to dark purple is clay layers with depths ranging from 40-60 meters. Meanwhile, the results of the GL-02 processing are shown in Fig. 6.

3.1.4 T4/Track 4, Medan Industrial Estate Area

There are 3 ranges of resistivity values in Track 4, namely 0Ω - 262Ω represented by dark blue graded to light green is sand. The 263Ω - 3.629Ω light green graded to light brown is sandy clay, while 3.630Ω > 8.710Ω light green color to deep purple is clay. The results of the track 4 processing are shown in Fig. 7.

3.2 Hydrochemical and Water Quality

Data interpretation was carried out based on the piper diagram results as shown in Fig. 8 where roman numerals I, II, III, IV, and V indicate the groundwater group. It was discovered that samples 3, 4, 6, 7, 8, 10, 11, 12, 13, 14, and 15 belong to the characteristics of group I, namely the carbonate hardness > 50%. This contains a high weak acid and alkaline earth as shown by the dominant concentration of HCO₃. Carbonate hardness is characterized by groundwater adjacent to identified based on anions and cations.
The analysis is performed by considering the dominant group from the data plot on the parallelogram, which is in the number area as shown in Table 1. This showed that sample points 1, 2, and have low carbonate or non-carbonate hardness. The other points have more than the sediment deposition zone near the sea. The samples 1, 2, and 5 belong to the characteristics of group V, where the non-carbonate hardness is more than 50%. Based on the piper diagram plot, the hydrochemical characteristics of groundwater can be 50% carbonate hardness groups, where the groundwater content is dominated by alkaline earth and weak acid.

Table 1. Hydrochemical Characteristics of Groundwater based on Anions and Cations

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Where C refers to 5 characteristics which are:
1. Carbonate hardness group >50% (high alkaline earth and weak acid content)
2. Low hardness group and the content of anions and cations <50%
3. The first alkali group with alkaline carbonate >50%
4. The first diversity group that has high salt content/strong alkali and acid content or the influence of seawater.
5. The group has low carbonate hardness, and second salt is >50% (not carbonate).

3.3 Data Analysis with Stiff Diagram Method

Fig. 9 showed the plotting result with stiff diagram where based on the cations, points 1, 3, 5, 9, 11, and according to anions, points 1 and 2 are dominated by chloride (Cl), while others are dominated by carbonate (CO₃) + bicarbonate (HCO₃).13 are dominated by magnesium (Mg), while 2, 4, 6, 7, 8, 10, 12, 14, and 15 are dominated by calcium (Ca).

3.4 Data Analysis with Durov Method

The Durov Diagram is an analytical method to identify groundwater facies and the process of effective mixing of groundwater with fresh water in the chemical evolution [25]. The water parameter is a grouping element using the Durov Diagram, as shown in Fig. 10. The groundwater facies consists of Ca-HCO₃ (4, 6, 7, 8, 10, 12, 14, 15), Mg-HCO₃ (3, 9, 11, 13), Mg-Cl (5, 2), and Ca-SO₄, where Ca-HCO₃ and Mg-HCO₃ indicate high water-karst rock interactions. The results showed the chloride content, electrical conductivity, the comparison price between chloride, the amount of CO₃ and HCO₃, as well as the anions and cations content using Trilinear Piper (1944), Stiff (1951), and Durov (1948). These methods were applied to determine the type and characteristics of the groundwater as explained below.
3.5 Comparative Price Content based on Chloride bicarbonate ratio.

The sampling results on drilled wells were conducted in the northern area of Medan City, namely in the Medan Belawan and Medan Labuhan Districts. Based on the Chloride Bicarbonate Ratio with the amount of CO3 and HCO3, the comparative price obtained varies between 0.027 to 1.114, where wells numbers 1 and 2 have values of 1.081 and 1.114, respectively.

3.6 Anion and Cation Contents

Based on the Stiff diagram results, the groundwater's dominant ion content is CO3+HCO3 compared to Mg. The Ca content is higher than the SO4 ion content, and the Cl content is more than Na. Generally, HCO3 in groundwater systems indicates the type of fresh water, while higher Cl- concentrations are influenced by seawater in coastal areas [26]. This is also supported by the relatively low electrical conductivity value with an average of 512 μmhos/cm, indicating that the sample is freshwater [27]. The groundwater tested in this study is included in the bicarbonate category because it has the dominant ion, namely HCO3[28].

The Piper diagram showed that the dominant ions in samples 1-15 are SO4 + Cl, Mg + Ca, and HCO3 + Cl. The value of Na and K is 0 because they are found in the sediment. The water content of the well is dominated by anions, namely Cl and HCO3, and Mg for cations. Moreover, Ca ions indicate water hardness with an average percentage of 67.68%. The content of HCO3 anions, with an average ion percentage of 74.89% indicates the presence of seawater intrusion that affects the quality of well water. In this study, the dominant anion in groundwater is HCO3, where one of the constituents of carbon dioxide in the waters is the bicarbonate ion (HCO-) other than carbon dioxide gas (CO2), carbonate ion (CO32-), and carbonic acid (H2CO3) [29]. The bicarbonate ions in the freshwater act as a buffer system and provide carbon for photosynthesis.

3.7 Water type analysis based on hydro-chemical facies analysis.

The results of laboratory analysis of groundwater samples in Medan Belawan District are presented in Table 3. According to [30], the elemental content in groundwater is closely related to the aquifer formation, the depositional environment during the formation, the composition, the processes, and the duration of groundwater. Generally, the samples used had major cations and anions dominated by alkaline and bicarbonate ions, respectively, as indicated by type I in the Piper diagram. The content that has the dominant concentration percent is Ca and HCO3. According to USGS, chloride most often comes from dissolved salts such as sodium chloride or Mg chloride. The groundwater facies in the study area include the Mg-HCO3, Ca-HCO3, Mg-Cl, and Ca-Cl facies. The results showed that the facies has a dominant content, namely Ca and HCO3 elements, as presented on the Piper and Stiff diagrams. Therefore, it can be stated that the groundwater in this study is included in the CaHCO3 facies. The CaHCO3 facies indicates that the dominant water has interacted with limestone and dolomite limestone CaCO3 from seawater can form limestone through a direct deposition process. Furthermore, the CaHCO3 facies dominated the study area, followed by the MgHCO3 facies, which indicates that the water has interacted with limestone and dolomite limestone [31].

3.8 Hydro-chemical Evolutionary Analysis

The hydro-chemical evolution analysis of groundwater was carried out by presenting data on the content of major ions in the Belawan District using a Piper diagram as presented in Fig. 8. Based on the presentation, it was discovered that the dominant cations type in groundwater is Ca, while for the anions, the major ion type is HCO3. This showed that hydro-geochemically, there is a change in the type of water from Mg-HCO3 to Ca-HCO3. This indicated an increase in rock or limestone deposits, causing high Ca content in groundwater. Afriani reported that groundwater at the sampling location belongs to a bicarbonate (I) group, which is obtained from Ca+, Mg2+, and high bicarbonate (HCO3-). The high content of bicarbonate and alkali such as Ca and Mg elements can increase water hardness. According to Cahyadi, these two elements are influenced by the condition of the aquifer, which is composed of deposited limestone bioclastic material.

The Mg content, which was initially dominated by CaCO3, indicates that groundwater has changed from salty to brackish and relatively little or no limestone rock.

3.9 Groundwater Quality Analysis Results

The laboratory tests were carried out to classify the geochemical conditions of the groundwater using the 15 samples. From the analysis of the water quality parameters, the chloride values of wells 1 and 2 reached 5.
205.08 and 203.2, respectively. Bicarbonate in both wells was 190.3 and 182.27, while DHL was 1307 and 1215. Furthermore, seawater intrusion can be identified with the chloride content of groundwater which will be included in the fresh brackish category at values 250 - 1000 mg/l. This is supported by large geoelectric data, where the resistivity value of 44Ω-128Ω and 129Ω-371Ω is interpreted as a sand layer that has experienced seawater intrusion at 40 meters depth (Track 1).

Furthermore, seawater intrusion can be identified locally regarding the interbeddings in the aquifer sector. In this case, further procedures are required to assess the geostatistics of the plotted elements' trends. Furthermore, concentration of HCO₃⁻, despite the absence of any appreciable statistical correlation with the chloride content of groundwater which will be divided into 5 groups, namely:

1. The first group consists of samples 3, 7, 8, 10, 11, 13, and 14. The group scores below average in all elements. This is indicated by the object's position in theopposite direction to all element vectors, which means it has a very small value in almost all elements.

2. The second group consists of samples 4, 5, 6, and 12. The characteristics of this group have values close to the average because the object's position is almost in the middle.

3. The third group consists of sample 9 and the characteristics have values below the average for all elements except CO₃⁻. This is indicated by the position of the object close to the CO₃⁻ direction.

4. The fourth group consists of samples 1 and 2. The characteristics of this group have values above the average for the elements Cl⁻ and Mg²⁺. This is shown by the sample's position in the same direction as the element.

5. The fifth group consists of sample 15, with characteristic values above the average for all variables. This is indicated by the position of the sample, which is located in the direction of all the elements.

4 Conclusion

The lithology of the measurement location consisted of 3 types, namely sand, clay sand, and clay. On the 1 and 2 tracks, it was interpreted as an area that had experienced seawater intrusion. Types of hydrogeochimical facies of groundwater in Medan Belawan District were Mg-HCO₃, Ca-HCO₃, Mg-Cl, and Ca-Cl. The dominant groundwater facies were Ca-HCO₃, followed by Mg-HCO₃. Therefore, groundwater in this study area was bicarbonate (I) type. The hydrogeochimical type or facies evolution of groundwater showed that the dominant cations type in Belawan District was Ca, while for the anions, the major ion type was HCO₃⁻. This indicated that hydrogeochemical, there was a change in the type of water from Mg-HCO₃ to Ca-HCO₃. This showed an increase in rock or limestone deposits, which caused high Ca content in groundwater. The results of the evolution of hydrogeochimical facies indicated a
seawater intrusion process due to the discovery of the element Cl. Based on the Piper and Stiff diagrams, it was discovered that the dominant elements were Ca, Mg, and HCO₃. This indicated the presence of lime or limestone deposits in the groundwater. The high alkali content can cause water hardness. One of the methods for treating water hardness is an ion exchanger.

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