Seawater intrusion analysis in the coastal region of Banda Aceh by using Geographic Information System (GIS)

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Abstract. Seawater intrusion is an environmental problem in many coastal regions which can harm the sustainability of groundwater resources in the future. Banda Aceh as the capital city of Aceh Province has a wide coastal region. The societies are mainly dependent on freshwater. Spatial Distribution of seawater intrusion has been studied using Geographic Information System (GIS) technique. In this research, 57 samples of groundwater were collected from 9 sub-districts of Banda Aceh. A portable Global Positioning System (GPS) was used to collect the coordinates of each sample site. This research aimed to analyse and generate the spatial distribution of seawater intrusion in Banda Aceh coastal region from the measurement of groundwater Electrical Conductivity (EC) and Total Dissolved Solids (TDS) values in the fields. The EC and TDS were used as indicators to assess the potential of seawater intrusion in the coastal aquifers. The results indicated that spatial distribution of seawater intrusion scattered in northern part of Banda Aceh. However, the analysis and measurements showed that the extent of EC and TDS values varied prominently across these sites, with the maximum EC value of 6.270 μS cm⁻¹ and TDS value of 4.420 mg l⁻¹ found at Neusu Aceh Village in Baiturrahman sub-district. Moreover, the minimum EC and TDS values of 217 μS cm⁻¹ and 100 mg l⁻¹, respectively, found at Mulia Village in Kuta Alam sub-district.

1. Introduction

Banda Aceh as the capital city of Aceh province is a coastal region. Banda Aceh is thoroughly used for various human activities, such as the centre of government, settlements, industry, ports, aquaculture, and tourism. Coastal aquifers can be the main source of clean water supply in coastal regions [1,2]. The community activities, both in land use and household waste disposal, has decreased the water quality. Moreover, the overexploitation of groundwater in a coastal region can cause seawater intrusion and the decline of groundwater quality [3].

Seawater intrusion is a process of penetration of seawater into the aquifers and contaminates its groundwater quality [4]. Seawater intrusion has become a global issue, exacerbated by increasing demands for freshwater in coastal regions. Seawater intrusion analysis is a complicated process. Various methods had been done by researchers to analyse the seawater intrusion process in the coastal
aquifer. The 2D resistivity method with Wenner-Schlumberger configuration was done to investigate seawater intrusion in East Surabaya [5]. In-situ measurement, laboratory test, and bicarbonate ratio of groundwater’s parameters were the common methods of evaluating the impact of seawater intrusion to the aquifers [6, 7, 8, 9]. The different model and method had been developed to assess the contaminated area by seawater intrusion such as GALDIT method [10].

The development of information technology has grown rapidly in this recent years. Geographic Information System (GIS) technique is broadly used in a variety of scientific applications. The use of SIG technique is able to facilitate the data analysis process. GIS can input, edit and analyze a lot of data in a short time. Nowadays, the integrated GIS and in-situ measurement of physico-chemical parameters of groundwater samples was generally applied to generate spatial distribution map of water quality to describe the area affected by seawater intrusion [11]. GIS and GALDIT method combination was conducted to assess seawater intrusion risk in a coastal aquifer [10]. Water resources problem like seawater intrusion can be solved modestly by using GIS [9]. Therefore, the purpose of this research is to analyse and produce the spatial distribution of seawater intrusion in Banda Aceh coastal region by using GIS.

1.1. Study Area

**Figure 1.** Banda Aceh as the study area.
Banda Aceh is the capital city of Aceh province. It is located on 5° 30' 45" – 5° 36' 16" latitude and 95° 22' 35" longitude. Figure 1 shows the study area. Banda Aceh is divided into 9 sub-districts, i.e. Syiah Kuala sub-district, Kuta Alam sub-district, Baiturrahman sub-district, Kuta Raja sub-district, Banda Raya sub-district, Jaya Baru sub-district, Lueng Bata sub-district, Meuraxa sub-district, and Ulee Kareng sub-district. The maximum value of groundwater parameters was found at Neusu Aceh Village in Baiturrahman sub-district.

2. Methods
Several samples at each location were measured by hand-held in-situ water quality testing equipment, namely EC and TDS meter. A handheld GPS was used to establish the ground points in the location, whose accuracies was 10 m. Water samples at each field station’s location were collected 0.5 m from surface waters well. We use the GIS software to interpolate EC and TDS values at each location. Interpolation is a process to predict the unknown values that lie in between the known data points. A precise interpolation method based on our prior research [11] have found that the Inverse Distance Weighted (IDW) was the best technique when compared to some other interpolation technique. Hence, the IDW interpolation method was applied to predict EC and TDS values at unknown locations. Similar methods employed in this research were applied by other researchers previously in various coastal regions in their countries [12,13,14]. Furthermore, an investigator also found that IDW was the best GIS interpolation method to analyse groundwater salinity and seawater intrusion in Banda Aceh coastal region [15]. A further explanation with various types of interpolation and their applications can be found in [11,16,17].

3. Results and Discussion
Prediction of sea water intrusion in Banda Aceh coastal region can be determined based on the spatial distribution pattern of groundwater parameters through the interpolation method available in the Geographic Information System (GIS).

3.1. Seawater intrusion
The Electrical Conductivity (EC) and Total Dissolved Solids (TDS) values of groundwater were measured to represent the contaminated areas impacted by seawater intrusion.

Result of the in-situ measurement and statistical analysis of groundwater parameters in the study area were shown in Table 1. It can be seen that distribution of data obtained at sample points in the study area was not normally distributed with large data variations. Figure 2 presented the spatial distribution of Electrical Conductivity (EC) observation values while the spatial distribution of Total Dissolved Solids (TDS) observation values were shown in figure 3.

Table 1. Statistics of groundwater parameters in Banda Aceh coastal region.

| Groundwater Parameter | Minimum Value | Maximum Value | Average value | Standard Deviation |
|-----------------------|---------------|---------------|---------------|--------------------|
| EC                    | 217 µS cm⁻¹   | 6.270 µS cm⁻¹ | 1208,14 µS cm⁻¹ | 1288,94            |
| TDS                   | 100 mg l⁻¹    | 4.420 mg l⁻¹  | 610,49 mg l⁻¹  | 786,21             |
Figure 2. Spatial distribution from Electrical Conductivity (EC) analysis result.
Figure 3. Spatial distribution from Total Dissolved Solids (TDS) analysis result.

3.2. Spatial analysis of seawater intrusion

An interpolation method by GIS was conducted to get the prediction values of EC and TDS at unsampled locations in the study area. Inverse Distance Weighted (IDW) is one of deterministic interpolation method which is available on GIS technique. IDW interpolation method explicitly implements the assumption that things which are close to one another are more alike than those that
are farther apart. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. The measured values closest to the prediction location have more influence on the predicted value than those farther away [16].

IDW is mostly applied interpolation method to assess groundwater quality based on its parameters [11,12,16]. IDW is also the best interpolation method based on GIS to estimate the spatial distribution of groundwater parameter related to seawater intrusion in Banda Aceh coastal region [14]. The interpolation results indicated that spatial distribution of seawater intrusion scattered in northern part of Banda Aceh.

Figure 4 illustrated that the result of EC spatial distribution pattern spread evenly over the output surface and the prediction values were centered in a circle. The minimum and maximum interpolation values of the interpolated results obtained were still within the range of the observation values.

Figure 5 showed that the result of IDW interpolation method for TDS produced the same pattern as the output surface of EC. The high values of TDS will increase the EC values of groundwater which can be used to identify the seawater intrusion affected area [6].

![Figure 4. Map of IDW interpolation result from Electrical Conductivity (EC).](image)

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Figure 5 showed that the result of IDW interpolation method for TDS produced the same pattern as the output surface of EC. The high values of TDS will increase the EC values of groundwater which can be used to identify the seawater intrusion affected area [6].

3.3 Spatial distribution of seawater intrusion
The EC and TDS parameters can directly indicate the salinity of groundwater and denote the aquifers affected by seawater intrusion. Relationship and classification of groundwater salinity levels based on the TDS and EC value was established by PAHIAA (Ad Hoc Committee of Seawater Intrusion) in Jakarta are shown in table 2.
Table 2. Classification of groundwater salinity level.

| Groundwater Salinity Level | TDS (mg l⁻¹) | EC (µS cm⁻¹) |
|----------------------------|--------------|--------------|
| Fresh water                | < 1.500      | < 1.500      |
| Slightly saline            | 1.500 – 3.000| 1.500 – 5.000|
| Moderately saline          | 3.000 – 10.000| 5.000 – 15.000|
| Saline                     | 10.000 – 35.000| 15.000 – 50.000|
| Brine                      | > 35.000     | > 50.000     |

The spatial distribution of seawater intrusion map was generated by using reclass feature in spatial analyst tools extension of GIS operations. The result of EC and TDS interpolation yielded three polygons (areas) as shown in figure 6 that illustrated three categories of seawater intrusion in the study area based on groundwater salinity level stated in table 2.

Figure 6. Spatial distribution of seawater intrusion in Banda Aceh coastal region.
4. Conclusions
This research concluded that GIS technique worked well in analyzing and generating the spatial distribution map of seawater intrusion in Banda Aceh coastal region. The results of the spatial analysis showed that there were indications of seawater intrusion in northern part of Banda Aceh. It was indicated by the high observations value and prediction value of groundwater parameters (EC and TDS) in that area. However, the analysis and measurements showed that the extent of groundwater parameters values varied prominently across these sites, with the maximum EC value of 6.270 µS cm⁻¹ and TDS value of 4.420 mg l⁻¹ found at Neusu Aceh Village in Baiturrahman sub-distict. In addition, the minimum EC and TDS values of 217 µS cm⁻¹ and 100 mg l⁻¹, respectively, found at Mulia Village in Kuta Alam sub-distict.

Geographic Information System (GIS) technique could also delineated the groundwater quality in the study area based on salinity level by using the IDW interpolation method and reclass feature in spatial analyst tool extension. Through the use of geo-statistical and spatial analysis capabilities of a GIS, it is possible to represent the three categories of groundwater quality in Banda Aceh coastal region related to salinity level, i.e. moderately saline, slightly saline, and freshwater.

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