Analysis of the distribution of seawater intrusion using electrical conductivity and total dissolved solid data and intelligence for residents in Sayung District, Demak Regency

K L Ariwibowo*, A M Riski¹, A S Fajarulloh¹ and T T Putranto¹
¹Department of Geological Engineering, Diponegoro University, Semarang, Jawa Tengah, Indonesia
*E-mail: kartikabasymeleh@gmail.com

Abstract. Massive groundwater extraction from production wells can trigger seawater intrusion, such as what happened in Sayung District, Demak. Seawater intrusion can be identified using quality analysis in the form of the electrical conductivity of each water sample taken. The research area is located in Sayung District, Demak Regency and is on the north coast, and is composed of alluvium quaternary deposits in the form of clay, sand sediments, and organic material of the plant. The purpose of this study is to determine the distribution of seawater intrusion in Sayung District and to know the prediction of the direction of seawater intrusion to provide an overview of groundwater quality recommendations in the study area to residents. To determine the distribution of seawater intrusion, you can use Electrical Conductivity and TDS (Total Dissolved Solids) data; from the results of the analysis, there is a decrease in groundwater quality as indicated by the electrical conductivity value in the range 2,800-3,265 μmhos/cm with slightly brackish salinity and damage levels categorized as critical and has a relatively high TDS value in the range 1,904-2,220.2 mg/L which is spread in the northern part near the coast including Timbulsloko and Sidorejo villages.

1. Introduction
Water is one of the most indispensable needs of every resident. With an increasing population every year, the increase in water demand will tend to increase. The dependence of the population on the use of groundwater is very high, this is due to the limited supply of groundwater which depends on the quality of groundwater, and the lack of interest in the population to use water by the PDAM (Local Water Supply Utility). It is feared that the increasing use of groundwater will exceed the limit of groundwater availability. Sayung District, Demak Regency is one of the coastal areas in the Central Java region, Indonesia (Figure 1.). This area has experienced events such as land subsidence as indicated by the relatively submerged houses of residents and there are cracks in road access and frequent tidal flooding with certain weather conditions (Figure 2.). The area is crossed by the sea so that the area is very potential for intrusion from seawater. For its use, the area has used groundwater from drilled wells, so that the water comes from a confined aquifer which can still be used for daily needs. One of the disasters that often occur in coastal areas is seawater intrusion. Where in that area, groundwater should be used for community use but cannot be used and is not suitable for use because the composition of groundwater has been changed by seawater intrusion. Seawater intrusion often occurs in areas close to the sea, which is caused by several factors, which can occur due to excessive groundwater extraction or
empty voids in a lithology. Sayung sub-district is a coastal area where one of the potential disasters is seawater intrusion. In this area, the sea level is almost approaching the plains in the sub-district. The purpose of the research conducted in Sayung sub-district is to determine the zoning of seawater intrusion in Sayung sub-district and provide recommendations to minimize the occurrence of intrusions. From this goal, it is hoped that it can be useful for something that may happen in the future.

2. Regional Geology
The regional geological conditions of the study area are included in the Magelang Semarang sheet [1] and the Kudus sheet [2]. Based on this, the oldest to youngest regional geological conditions are composed of two types of rock, namely Tertiary sedimentary rocks, namely the Kerek and Kalibeng Formations, then the Damar Formation and the Kaligetas Formation which are Quaternary age and surface sediments (alluvium) which are Holocene age. The Kerek and Kalibeng Formations are predominantly composed of claystone, marl, and local limestone. The formation is located on low to medium slope morphology. The Damar Formation is composed of conglomerates, tuff sandstones. Volcanic breccias are in the form of lava and are located in morphology with moderate slopes, while the Kaligetas Formation is composed of dominant volcanic products such as volcanic breccias, lava, and tuff sandstones, and local claystone. This formation is spread over morphology with moderate to high slopes. The plains area is dominated by coastal alluvium deposits, rivers, and lakes, consisting of clay, silt, sand, and gravel [3].

Figure 1. The location of Sayung District, Demak Regency, Central Java, Indonesia.

Figure 2. (A) The condition of the house which is affected by land subsidence; (B) The condition of the research area affected by tidal flooding.
3. Methodology

In doing research on the distribution of seawater intrusion that occurs in Demak, some data is needed including geological data of the research area, measurement of elevation for taking wells, and depth data of boreholes to calculate the value of the groundwater level using MS Excel 2013 software. In addition, water samples were taken to test their electrical conductivity using an electrical conductivity meter. Then the data that has been obtained will be processed using Surfer 13 to find out 3D conditions under the surface and using ArcMap 10.5 software to determine the distribution of each parameter needed in determining the distribution of intrusion, including geological maps, electrical conductivity distribution map, total dissolved solid distribution map, groundwater map. To analyze the distribution of each map using the IDW (Inverse Distance Weighted) data interpolation method is a simple method of determination by considering the surrounding points [4], where the interpolation value will be more similar to the closer sample data [5].

![Flowchart of the research](image-url)
4. Result and Discussion

4.1. Geological Conditions

The state of lithology in Sayung sub-district is an alluvium lithology. This area is a coastal area of the Central Java region. The lithology is a collection of several materials transported from the area.

![Image showing alluvium deposits](image1.png)

Figure 4. The research area there are alluvium deposits.

Based on the regional geology, the area is included in the alluvium formation which is in the north and approaches the Java Sea. The lithological composition in the area is the presence of clay minerals with the size of clay, sand grains, clastic sedimentary material, and plant deposits as well as the presence of organic material because the area is close to the swampy area of origin.

![Geological Map of Sayung District, Demak Regency](image2.png)

Figure 5. The research area there are alluvium deposits.
4.2. Groundwater Elevation Map

The state of groundwater elevation in the research area is by examining the depth of the borewell because the research area has not used dug wells for its water source so that it does not find dug wells to determine the groundwater level. Groundwater elevation data was collected directly using field survey methods and interviews with residents who owned boreholes. So that it can be estimated about the depth of the wells in the study area. In the study area, it was found that the depth range of the groundwater elevation table was 60 to 120 meters below the surface (Figure 6B).

At the groundwater level, it forms a flow pattern leading to the respective wells (Table 1.). In the southwest part of the research area, the direction of the flow of the groundwater elevation is towards the sea, while in the eastern area of the study area the direction of flow is dominant towards the northeast to the north of the study area. Based on the area, the direction of groundwater flow in the confined aquifer is towards Bedono and partly towards the Banjarsari sub-district (Figure 6A). A 3-dimensional illustration of the high and low groundwater level conditions can be seen in Figure 6A. If the red area shows that the groundwater level is high or relatively close to the surface and will flow to the lower area, it is shown in blue The lowest contour value is -130 meters while the contour value the highest is -50 meters (Figure 6A).

Figure 6. (A) 3D appearance of groundwater surface conditions; (B) The groundwater map of the research area.
Table 1. Groundwater surface coordinate point in the study area.

| Coordinate X | Coordinate Y | Groundwater Level (m) |
|--------------|--------------|-----------------------|
| 447818       | 9236106      | 90                    |
| 446770       | 9236873      | 90                    |
| 445895       | 9238004      | 120                   |
| 443071       | 9234311      | 120                   |
| 442922       | 9234320      | 100                   |
| 443599       | 9234572      | 110                   |
| 443641       | 9234502      | 100                   |
| 442905       | 9235442      | 125                   |
| 442908       | 9234265      | 100                   |
| 442842       | 9233944      | 100                   |
| 443335       | 9234028      | 125                   |
| 448531       | 9235928      | 90                    |
| 448196       | 9236523      | 100                   |
| 447846       | 9237126      | 82                    |
| 447101       | 9237319      | 85                    |
| 449488.6     | 9237752      | 102                   |
| 449324.8     | 9236230      | 105                   |
| 448160.7     | 9236529      | 120                   |
| 448516.2     | 9237942      | 120                   |
| 448942.5     | 9239884      | 125                   |
| 450071.7     | 9239277      | 120                   |
| 449400.8     | 9238690      | 120                   |
| 448604.5     | 9238282      | 125                   |

Figure 7. One of the drilled wells in the study area.

4.3. Electrical Conductivity and Total Dissolved Solid
Based on the value of Electrical Conductivity and Total Dissolved Solid (TDS), the research area includes groundwater quality in the form of fresh and slightly brackish water [6]. The classification is based on the value obtained from the measurement results of water samples in boreholes in the study...
area. Based on the results (Table 2) which have been presented, it can be seen that the distribution of groundwater content with a high electrical conductivity value is shown in dark green (Figure 8B) and a high TDS value is shown in dark red (Figure 9B), the distribution of these conditions is in Sidorejo Village, Tugu Village and Timbusloko Village, this is interpreted by the quality content of groundwater that has been mixed with seawater or it can be indicated that the area has experienced seawater intrusion and is supported by the groundwater content in the area which is included in the type of groundwater quality which is rather brackish. In addition, in several villages, namely Banjarsari Village, Sidodadi Village, Bedono Village, and Sidogemah Village, they tend to have a low electrical conductivity value content as shown in light green (Figure 8B.) and have a low TDS value content as shown in pink. (Figure 9B.), this shows that in these areas the quality of groundwater contained is still not many signs of seawater intrusion and based on its quality it is still included in freshwater.

Table 2. TDS coordinate points and electrical conductivity in the study area.

| Coordinate X | Coordinate Y | TDS (mg/L) | Electrical Conductivity (µmhos/cm) |
|--------------|--------------|------------|-----------------------------------|
| 443071       | 9234311      | 465.8      | 685                                |
| 442922       | 9234320      | 541.28     | 796                                |
| 443599       | 9234572      | 469.88     | 691                                |
| 443641       | 9234502      | 999.6      | 1,470                              |
| 442905       | 9235442      | 553.52     | 814                                |
| 442908       | 9234265      | 394.4      | 580                                |
| 442842       | 9233944      | 425.68     | 626                                |
| 443335       | 9234028      | 427.04     | 628                                |
| 448531       | 9235928      | 705.16     | 1,037                              |
| 448196       | 9236523      | 577.32     | 849                                |
| 447846       | 9237126      | 687.48     | 1,011                              |
| 447101       | 9237319      | 1904       | 2,800                              |
| 449489       | 9237752      | 2220.2     | 3,265                              |
| 448161       | 9236529      | 490.96     | 722                                |
| 448516       | 9237942      | 2097.8     | 3,085                              |
| 448943       | 9239884      | 732.36     | 1,077                              |
| 450072       | 9239277      | 867        | 1,275                              |
| 449401       | 9238690      | 592.28     | 871                                |
| 448605       | 9238282      | 636.48     | 936                                |
4.4. Seawater Intrusion Vulnerability Zone Analysis

Seawater intrusion is the infiltration of seawater into the ground or the process of entering seawater into groundwater. This intrusion can be identified using data from electrical conductivity and TDS (total dissolved solid). If the values of electrical conductivity and TDS are in the high category, there will be a decrease in groundwater quality. Usually, seawater intrusion is found in wells near the coast which is triggered by large amounts of groundwater withdrawal [7]. Analysis of the seawater intrusion vulnerability zone uses weighting analyzed by ArcMap 10.5.
The parameters used in the weighting include the distribution of lithology, distribution of electrical conductivity values in the study area, and distribution of TDS values. The values of electrical conductivity and TDS measured in the field are in class 2 and class 1 (Table 3.). The measured electrical conductivity values ranged from 580 – 3,265 µmhos/cm, while the TDS ranged from 394.4 to 2,220.2 mg/L. So, that is categorized into 2 classifications of vulnerability, namely class 1 which is categorized as safe, and class 2 which is categorized as vulnerable. Meanwhile, the lithological condition in the form of alluvium is very influencing so that it has the highest value. To produce a visualization map of the intrusion distribution, the map that has been classified into 2 classes of each parameter is overlaid using a weighted percentage.

Figure 9. (A) The total dissolved solid map of the research area; (B) 3D Appearance of total dissolved value
Table 3. Weighted value of electrical conductivity and Total Dissolved Solid

| Electrical Conductivity (µmhos/cm) | TDS (mg/L) | Value of weighting calculation |
|-----------------------------------|------------|--------------------------------|
| <1,500                            | <1,000     | Class 1                        |
| 1,500-5,000                       | 1,000-3,000| Class 2                        |
| 5,000-15,000                      | 3,000-10,000| Class 3                       |
| 15,000-50,000                     | 10,000-35,000| Class 4                      |
| >50,000                           | >35,000    | Class 5                        |

The highest percentage of weighting (Table 4.) is 40% for lithology maps, 30% for electrical conductivity maps, and 30% for TDS maps. The lithology map has the greatest influence because the lithology of the study area consists of alluvium deposits which form swampy areas that are inundated by seawater, brackish water, and freshwater so that it further accelerates the aquifer layer to be entered by water with high salinity. The weighted value of electrical conductivity and TDS has the same value, namely 30%, the two values are related to each other, water with high salinity will more easily flow electric current so that the electrical conductivity is high. While the TDS value is obtained from the calculation of the electrical conductivity value formula. From the calculation analysis using ArcMap 10.5, it is obtained 3 classifications that identify that there are 3 seawater intrusion zoning in the study area including safe, moderate, and trouble zones. The safe zone is marked with a green area covering the villages of Banjarsari, Tugu, Sidogemah, and Bendowo. The zone being shown is a yellow area covering the northern part of Surodadi Village. Meanwhile, the vulnerable areas marked with red residents include the villages of Surodadi, Timbulsloko, and Sidorejo (Figure 10.).

Table 4. Weighted value for sea water intrusion zoning

| Parameter                                    | Percentage |
|----------------------------------------------|------------|
| Lithology                                    | 40%        |
| Electrical Conductivity                      | 30%        |
| Total Dissolved Solid (TDS)                  | 30%        |

Figure 10. Seawater Intrusion Vulnerability Zone Map
4.5 Simple Water Treatment Intelligence

The condition around the research area is an area close to the north coast and areas that are mostly surrounded by swamps or areas of brackish water and freshwater. Residents' houses are built on areas that are inundated by water and residents build houses using the landfill method. However, this area is an area of tidal flooding or seawater entering the land due to the high sea level [8]. Geologically, this area is composed of alluvial deposits so that the soil conditions in the Sayung area are quite unstable and land subsidence is marked by several resident's houses that are abandoned due to drowning, as well as several residents' houses that have to be landfilled every year.

Based on these conditions, Sayung residents can only get water sources from confined aquifers or use artesian wells to get clean water. In fact, there are several wells that produce water with the physical characteristics of the water being slightly yellow and tasting salty. Based on interviews with the Village Head of Sidorejo, some residents often find it difficult to find water for drinking and require buying water with unstable economic conditions, this is quite a problem in several villages in Sayung District.

After studying social problems in the research area, a simple right solution that can help residents around the research area is considered. Identified groundwater is water with brackish characteristics in Tugu Village and Sidorejo Village based on the PAHIAA classification. Brackish water tends to have a high solute content, the chemical content of brackish water includes sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺), chloride (Cl⁻), sulfate (SO₄²⁻), and bicarbonate (HCO₃⁻) in water [9]. The salty taste of brackish water is caused by the high salinity of the water, if water is consumed daily it can cause health problems in the future. So it is necessary to handle it so that water can still be used for drinking needs. In addition, the existence of this simple filter reactor can help residents understand that surface water that has not been contaminated by chemical waste can still be used for bathing needs can be filtered so that this recommendation can reduce water intake through deep wells (bores) to suppress seawater intrusion. This treatment can take advantage of the adsorbent properties of natural zeolites. Zeolite has a high adsorbing ability because it has pores that can exchange high cations, which are hydrated alumino-silicates with cations of sodium, potassium, and barium [10]. The filter reactor to filter brackish water requires simple materials using activated charcoal, zeolite, silica sand, and gravel (Figure 11D.). These materials are made for filtration prototypes with a ratio of charcoal, zeolite, sand, gravel is 4: 4: 3: 2 [11].

Socialization in an effort to educate residents in the research area is descriptive of the results of data processing carried out by the delivery method in the form of door-to-door with the aim of implementing health protocols during the COVID-19 pandemic. In addition, this effort is very helpful in providing insight to residents regarding the condition of the research area that has been affected by the seawater intrusion process so that it can provide recommendations in order to minimize the use of boreholes which are interpreted as sustainable intrusions in the future (Figure 11.).

5. Conclusion

The research area which is included in the coastal area of Sayung District, Demak Regency generally has lithological conditions in the form of alluvium deposits and is supported by field conditions that experience subsidence of land level, tidal flooding, and roads that have cracks. Based on field data processing, the value of electrical conductivity, and total dissolved solids, there are three well points that have been indicated to experience seawater intrusion, namely around the villages of Sidorejo, Tugu, and Timbulsloko. To prevent and minimize the occurrence of sustainable seawater intrusion, intelligence and understanding of seawater intrusion and recommendations for the use of reactor filters are carried out.
Figure 11. Socialization with the door to door method in the research area. (A) The process of water filtration using a simple reactor filter, (B) The process of intelligence and socialization of sea water intrusion to residents of Sayung District, (C) The process of intelligence and socialization of sea water intrusion to residents of Sayung District, (D) Design of a filter or simple reactor filter.

Acknowledgments
We would like to thank the lecturers of the Geological Engineering Department, Faculty of Engineering, Diponegoro University who have guided the authors to carry out this research.

References
[1] Thanden and Sumadirja 1996 Peta Geologi lembar Magelang dan Semarang (Bandung: Direktorat Badan Geologi ESDM)
[2] Suwarti T and Wikarno R 1992 Peta Geologi Lembar Kudus Skala 1 : 100.000 (Bandung: Pusat Penelitian dan Pengembangan Geologi)
[3] Marfai M A Cahyadi A Krisnantara G Gustiar G G 2015 Karakteristik Hidrogeokimia Airtanah di Pesisir Kabupaten Demak, Jawa Tengah (Seminar Nasional Pekan Ilmiah)
[4] NCGI 2007 Interpolation: Inverse Distance Weighting www.ncgia.ucsb.edu/pubs/
[5] Pramono G H 2008 Akurasi metode IDW dan kriging untuk interpolasi sebaran sedimen tersuspensi. In Forum geografi 22 L 97-110
[6] PAHAAI 1986 Klasifikasi Keasian Perairan (Jakarta: Panitia Ad Hoc Intrusi Air Asin Jakarta)
[7] Waspodo R S B Kusumarni S Dewi V A K 2019 Prediksi Intrusi Air Laut Berdasarkan Nilai Daya Hantar Listrik dan Total Dissolved Solid di Kabupaten Tangerang. Journal of Agricultural Engineering, 81 L 243-250
[8] Rahmawan L E Yuwono B D Awaluddin M 2016 Survei Pemantauan Deformasi Muka Tanah Kawasan Pesisir Menggunakan Metode Pengukuran GPS Di Kabupaten Demak Tahun 2016 (Studi Kasus: Pesisir Kecamatan Sayung, Demak). Jurnal Geodesi Undip, 5(4)L 4455
[9] Aziza F N Latifah L Kusumastuti E 2014 Pemanfaatan Zeolit Alam Teraktivasi Ammonium Nitrat (NH4NO3) Untuk Menurunkan Salinitas Air Sumur Payau. *Indonesian Journal of Chemical Science, 3*(3)

[10] Khiqmah N V 2015 *Pengembangan Teknik Adsorpsi dengan Menggunakan Ion Exchanger Berbasis Zeolit-Karbon Aktif untuk Produksi Air Sanitasi* (Development of Adsorption Techniques Using the Ion Exchanger Zeolite-Based Activated Carbon for the Production Sanitation Water) (Semarang: Doctoral dissertation, Diponegoro University)

[11] Hamidah L N Rahmayanti A 2018 Pemanfaatan Zeolit dan KarbonAktif dalam Menurunkan Jumlah Bakteri pada Filter Pengolah Air Payau. *In Conference Proceeding on Waste Treatment Technology 1* L 113-118