Seawater Intrusion Assessment based on Hydrochemical Data in Gapura Sub-district of Sumenep Regency, East Java, Indonesia

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Abstract. Gapura is a sub-district with a large salt pond in Sumenep Regency, Madura Island, Indonesia. In this area, many residents’ houses have drilled wells to meet their water needs. One factor is that Municipal Waterwork (PDAM) does not reach the area due to limited water sources and difficult accessibility. Residents in the area claimed to have found some groundwater that tasted brackish. This study aims to apply hydrochemical analysis to identify the possibility of seawater intrusion in the area. The assessment of seawater intrusion uses the total dissolved solids (TDS) value and major ion of groundwater samples. In the analysis of thirty samples, two samples have different values from the samples of freshwater. However, the value of these two samples is relatively low to be classified as seawater intrusion. It is described on the TDS values that belong to the class of brackish water, from Simpson ratio values classified as slightly contaminated, and from the piper diagram plot that is still in the mixing zone in the middle of the diagram. The presence of brackish water in these samples can be caused by a location close to salt pond activities.

1. Introduction

According to data from the Ministry of Maritime and Fisheries Affairs, Sumenep Regency, Madura Island, is one of the highest salt producers in Indonesia [1]. Gapura is one of the sub-districts in Sumenep Regency as a salt production center because this sub-district is a coastal area [2]. Most of the residents in this area used groundwater as a source for daily purposes by drilling wells. The clean water network from Municipal Waterwork (PDAM) is not available due to limited sources and difficulties of accessibility. It has been found some brackish groundwater according to resident information since several years ago. The coastal area is prone to groundwater pollution due to the meeting area between the plains and the ocean. All water, both surface water, and groundwater will be discharged in this area. Therefore, all pollutants carried by the water media will end up in the coastal zone [3]. Many coastal aquifers face anthropogenic impacts are urbanization, industrialization, and agricultural activities. It has...
causing seawater intrusion. Therefore, a sustainable groundwater management strategy must address the situation [4]. Hydrochemistry is an interdisciplinary science that deals with water chemistry in the natural environment [5]. The use of hydrochemical for tracing the origin of salinity of groundwater is a robust methodology that enables the identification of multiple salinity sources in coastal aquifers [6]. Hence, it is essential to study groundwater in appraising its hydrochemistry and contamination influences [5].

The research was conducted to determine the presence of brackish water due to seawater intrusion in Gapura, as information on the decline in groundwater quality, especially shallow groundwater so that it can be helpful as an action to prevent the spread of brackish water in groundwater.

2. Methodology

The study was conducted in Gapura Sub-district, Sumenep Regency, Madura Island. The geology of the research site is composed of limestone, sandstone, and alluvial deposits, as shown in Figure 1. The morphology in this area is in the form of karst plains and tidal plains. The research area is a coastal area with a large salt pond used as a salt production center.

This research was conducted by groundwater sampling and chemical analysis of groundwater samples. There are 30 groundwater samples collected from the field, hoping to represent groundwater characteristics at each location, as shown in Figure 1. TDS (total dissolved solids) was measured using

![Figure 1. Geological Map of the research area [7]](image-url)
Hanna Instrument. Groundwater sampling was carried out for analysis of major ion concentrations in the laboratory. The samples were analyzed for ion composition, including cation elements (Na\(^+\), K\(^+\), Ca\(^{2+}\), Mg\(^{2+}\)) and anion elements (Cl\(^-\), HCO\(_3\)\(^-\), CO\(_3^{2-}\), and SO\(_4^{2-}\)) based on the national standard of Indonesia (SNI).

The chemical composition of water was used to analyze seawater intrusion indication based on the TDS value, Simpson ratio, and piper diagram. The TDS value at each observation point was used to determine saline groundwater distribution using saline groundwater classification. The classification of TDS value is shown in Table 1.

| Water class | TDS (mg/L) |
|-------------|------------|
| Fresh       | <1,000     |
| Brackish    | 1,000 – 10,000 |
| Saline      | 10,000 – 100,000 |
| Brine       | >100,000   |

The Simpson ratio method is based on the concentrations of Cl\(^-\), HCO\(_3\)\(^-\), and CO\(_3^{2-}\) [9], the following equation:

\[
\text{Simpson ratio} = \frac{\text{Cl}}{\text{HCO}_3^- + \text{CO}_3^{2-}}
\] (1)

Five classes were created to evaluate the level of contamination, as listed in Table 2.

| Level of contamination | Simpson ratio value |
|------------------------|---------------------|
| Good condition         | <0.5                |
| Slightly contaminated  | 0.5 – 1.3           |
| Moderately contaminated| 1.3 – 2.8           |
| Injuriously contaminated| 2.8 – 6.6         |
| Highly contaminated    | 6.6 – 15.5          |

The results of the major ion analysis are then visualized in a piper trilinear diagram to determine the genesis of groundwater [9]. The result can be divided into four groundwater classes: Calcium Magnesium Bicarbonate, Alkali Bicarbonate, Calcium Magnesium Chloride, and Alkali Chloride. The facies division for cations includes magnesium (Mg), sodium (Na+K), and calcium (Ca), while the facies for anions include sulfate (SO\(_4^{2-}\)), bicarbonate (CO\(_3^{2-}\)+HCO\(_3\)\(^-\)), and chloride (Cl) [10].

3. Result and Discussion

Hydrochemical data shows that TDS values of the samples range from 90 mg/L to 1,210 mg/L, with the highest value in sample 3 reach 1,210 mg/L. Two samples (3 and 18) are classified as brackish water since their TDS are higher than 1,000 mg/L, as presented in Table 3.
| Sample | Cations (mg/L) | Anions (mg/L) | TDS (mg/L) | Simpson ratio value | Level of Contamination |
|--------|----------------|---------------|------------|--------------------|-----------------------|
|        | Na⁺ | K⁺ | Ca²⁺ | Mg²⁺ | Cl⁻ | NO₃⁻ | SO₄²⁻ | HCO₃⁻ | CO₃²⁻ |         |        |
| 1      | 27.6 | 29.8 | 109.8 | 12.8 | 24.9 | 0.69 | 42.8 | 326 | N.D. | 430 | 0.08 | Good |
| 2      | 47.1 | 2.7 | 118.5 | 18.3 | 58.6 | 0.2 | 43.4 | 368 | N.D. | 520 | 0.16 | Good |
| 3      | 245.2 | 38 | 118.2 | 39.6 | 432.8 | 0.67 | 97.3 | 391 | N.D. | 1210 | 1.11 | Slightly contaminated |
| 4      | 89.2 | 24.4 | 105 | 20.7 | 97.5 | 0.42 | 49.1 | 432 | N.D. | 590 | 0.23 | Good |
| 5      | 20.7 | 3 | 103.4 | 7.9 | 23.6 | 0.69 | 31.2 | 280 | N.D. | 350 | 0.08 | Good |
| 6      | 4.3 | 3.2 | 79.6 | 2.4 | 4.5 | 0.5 | 6.4 | 372 | N.D. | 210 | 0.01 | Good |
| 7      | 59.6 | 33.6 | 121.8 | 8.8 | 63.7 | 0.78 | 46.8 | 336 | N.D. | 540 | 0.19 | Good |
| 8      | 50.7 | 1.9 | 91.5 | 13.5 | 99.4 | 0.53 | 59 | 405 | N.D. | 480 | 0.25 | Good |
| 9      | 11.3 | 6.7 | 97.5 | 8.1 | 3.8 | 0 | 3 | 345 | N.D. | 320 | 0.01 | Good |
| 10     | 21.5 | 1 | 113.6 | 23.1 | 22.3 | 0 | 15.5 | 349 | N.D. | 460 | 0.06 | Good |
| 11     | 27.7 | 4.3 | 72.3 | 7.8 | 35.7 | 0.23 | 32.5 | 345 | N.D. | 270 | 0.10 | Good |
| 12     | 9.9 | 0.8 | 49.7 | 7.6 | 3.2 | 0 | 26.6 | 340 | N.D. | 150 | 0.01 | Good |
| 13     | 8.6 | 1.6 | 110.1 | 3.9 | 6.4 | 0 | 9.75 | 299 | N.D. | 330 | 0.02 | Good |
| 14     | 46 | 14.1 | 40.5 | 4.3 | 36.3 | 0 | 43.8 | 290 | N.D. | 220 | 0.13 | Good |
| 15     | 38.1 | 43.7 | 93.6 | 21.6 | 76.5 | 0.06 | 79.5 | 372 | N.D. | 90 | 0.21 | Good |
| 16     | 34.7 | 8.1 | 86.9 | 13.7 | 57.4 | 0 | 49.5 | 368 | N.D. | 530 | 0.16 | Good |
| 17     | 49.7 | 1.9 | 92.5 | 16.4 | 116 | 0.33 | 55 | 377 | N.D. | 520 | 0.31 | Good |
| 18     | 264.4 | 5.7 | 114 | 32.8 | 247.3 | 0 | 26.8 | 322 | N.D. | 1040 | 0.77 | Slightly contaminated |
| 19     | 79.6 | 23.3 | 88.7 | 20.2 | 95.6 | 0.67 | 24.6 | 368 | N.D. | 510 | 0.26 | Good |
| 20     | 104.7 | 25.6 | 107.6 | 22.3 | 148.5 | 0.62 | 52.9 | 313 | N.D. | 590 | 0.47 | Good |
| 21     | 82.8 | 23.4 | 110.4 | 15.8 | 70.8 | 0 | 42.5 | 294 | N.D. | 560 | 0.24 | Good |
| 22     | 26.8 | 6 | 95.4 | 16.8 | 33.1 | 0.31 | 18.5 | 303 | N.D. | 390 | 0.11 | Good |
| 23     | 20.3 | 1.5 | 94.1 | 18.5 | 8.9 | 0 | 4.4 | 331 | N.D. | 380 | 0.03 | Good |
| 24     | 11.9 | 2.3 | 99.4 | 2.5 | 12.1 | 0.31 | 4 | 299 | N.D. | 230 | 0.04 | Good |
| 25     | 19.6 | 3.2 | 63.6 | 4.2 | 7.7 | 0 | 0 | 276 | N.D. | 200 | 0.03 | Good |
| 26     | 18 | 0.5 | 68 | 10.3 | 16.6 | 0 | 11.6 | 345 | N.D. | 290 | 0.05 | Good |
| 27     | 8.2 | 1.3 | 73.6 | 3.9 | 6.4 | 0 | 0 | 391 | N.D. | 260 | 0.02 | Good |
| 28     | 26.3 | 6.2 | 115.4 | 28.7 | 38.2 | 0 | 45.6 | 336 | N.D. | 510 | 0.11 | Good |
| 29     | 3.9 | 4.5 | 69.8 | 4.6 | 6.4 | 0.06 | 0 | 349 | N.D. | 140 | 0.02 | Good |
| 30     | 52.7 | 29.4 | 92.4 | 14.1 | 70.1 | 0.95 | 27.8 | N.D. | 470 | 0.25 | Good |

Note: N.D. = Not detected
The Simpson ratio value indicates most of the values are below 0.5 and categorized as good condition. Only two samples (3 and 18) have the Simpson value higher than 0.5 and are classified as slightly contaminated, as shown in Table 3.

Based on the result of the piper diagram, most of the water types in the study area were dominated by calcium magnesium bicarbonate, which means the concentration of Ca+Mg is greater than the concentration of Na+K, and the concentration of HCO_3 is greater than the concentration of Cl. Only two samples (3 and 18) are alkaline chloride. It means the two samples have the concentration of Na+K greater than the concentration of Ca+Mg, and the concentration of Cl greater than the concentration of HCO_3, as shown in Figure 2.

4. Conclusion

Hydrochemical data in Gapura Sub-district show it has two groundwater groups: freshwater and brackish (samples 3 and 18). However, the value of these two samples is relatively low to be classified as seawater intrusion. As described in the result, 93% of samples have a TDS value below 1,000 ppm, and all of them are classified as a good condition since their Simpson value index is below 0.5. It is also described by the piper diagram plot that most of the groundwater types in the study area were dominated by calcium magnesium bicarbonate. Although two samples (3 and 18) are alkaline chlorides, the plot is still in the mixing zone at the middle of the diagram, which means the chloride concentration in those samples is still relatively small. Salt ponds production around the well is probably the source of brackish groundwater from the two samples with a high TDS value.
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