Determination of Saltwater Intrusion Zone Based on Groundwater Physical Properties on Eretan Coastal Area Indramayu Jawa Barat

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Abstract. The research area is a coastal area that has great groundwater potential. However, if the management is not appropriate then it can cause saltwater intrusion problem. This condition can be indicated by the value of EC, TDS, pH and temperature. The greater EC and TDS value indicated the higher saltwater intrusion. From 40 measurement points conducted in 18 wells obtained the lowest value of the TDS 520 mg/L at SG10 at 1.21 masl and the highest value 3580 mg/L at SG12 at 0.5 masl. As for the lowest value of EC 1050 μS/cm at SG10 at 1.21 masl and highest value 7050 S/cm at SG12 at 0.5 masl. Based on the research there is a points of anomaly that have higher EC and TDS than the surrounding area. This anomaly shows that at these points there has been overpumping and classified into the highest saltwater intrusion zone that requiring monitoring.

1. Introduction
Groundwater is the primary source to fulfill the requisite of clean water in human life, so the quality and quantity of groundwater must be maintained. The level of clean water supply is highly dependent on the quality and quantity of ground water in a region so as to meet the water needs of the area and surrounding areas. Groundwater retrieval in coastal areas can lead to intrusion of sea water, or entry of sea water into freshwater [1]. This condition of groundwater instability can cause the intrusion of sea water into groundwater so that freshwater becomes brackish and unfit for consumption [2].

The research area located on Eretan Kulon Village is a coastal area that has the potential for seawater intrusion, because in that area a lot of development is done, especially the development of kongsi (harbor and place of sale of seafood) which is accompanied by the increase of settlement and the increasing of clean water requirement, this may lead to excessive pumping which may affect the stability of the pressure between freshwater and saltwater [3]. This study is intended to determine the level of intrusion that occurs in the research area and grouping into zones based on the level of intrusion. So that can be more effective groundwater management.
1.1. Research Area
The research area administratively including to Kandanghaur Sub-district, Indramayu District, West Java Province, Indonesia. Geographically located at 108° 04' 00" - 108° 05' 45" East Longitude and 6° 19' 00" - 6° 20' 05" South Latitude.

2. Methods
Data collection is done by measuring directly on shallow groundwater conditions on Eretan Kulon Village and surrounding areas with depth of the groundwater wells mostly ranges from 1 m to 4 m. Obtained 40 points of data from 18 wells found in the study area. Physical properties of groundwater test is conducted using digital multi parameter tool. Elevation measurements were made with an altimeter tool previously calibrated with sea level in the study area. The location of sample taken with GPS device. Then from groundwater level data is made iso-phreatic map to know the direction of groundwater flow and to know the interaction between groundwater and surface water. After that the groundwater physical properties data is analyzed by looking at how it spreads, vertically and horizontally. Then the data distribution value of each parameters of the physical properties of groundwater are connected to each other to determine the condition of groundwater in the area against sea water intrusion that occurred in the area and the factors that influence it. The value of TDS and EC then classify followed Davis and De Wiest, 1996 to identify the level of seawater intrusion on the research area [4].

3. Results

3.1. Result from The Measurement of Groundwater Physical Properties
From the measurement obtained data as in table 1.

3.2. Direction of Groundwater Flow And Groundwater Interactions with Surface Water
Based on research conducted groundwater depth in the research area from 18 wells point is ranged from 1.87 mdpl to 0.95 mdpl. The relationship between points that have the same groundwater level is illustrated with iso-phreatic maps in figure 1. Iso-phreatic Map of The Research Area.

| No | Elevasi (mdpl) | Depth of Well (m) | Groundwater Surface (mdpl) | TDS (mg/L) | pH | Water Temperature (°C) | Air Temperature (°C) |
|----|----------------|-------------------|----------------------------|------------|----|------------------------|----------------------|
| SG 1 | 2 | 1.05 | 0.95 | 2450 | Slightly Saline | 4900 | 7.1 | 29.1 | 28.5 |
|   |    | 2.27 | -0.27 | 3400 | Moderately Saline | 6610 | 7.2 | 29.8 | 30.6 |
| SG 2 | 2 | 0.65 | 1.45 | 3409 | Moderately Saline | 6753 | 7.2 | 29.4 | 30 |
|   |    | 2.12 | -0.12 | 3505 | Moderately Saline | 7003 | 7.2 | 29.8 | 30.1 |
| SG 3 | 2 | 0.85 | 1.15 | 1859 | Slightly Saline | 3714 | 7.1 | 29.4 | 30 |
|   |    | 2.12 | -0.12 | 2584 | Slightly Saline | 5097 | 7.1 | 29.7 | 30 |
|   |    | 3.12 | -1.12 | 3459 | Moderately Saline | 7006 | 7.3 | 30 | 32.3 |
| SG  | 2   | 0.7  | 1.3  | 1974 | Slightly Saline | 3897 | 7.1  | 28.4 | 30.4 |
|     |     | 2.28 | -0.28| 2944 | Slightly Saline | 5883 | 7.2  | 28.9 | 30.7 |
| SG  | 2   | 0.84 | 1.16 | 1798 | Slightly Saline | 3601 | 7.1  | 29.6 | 30.8 |
|     |     | 2.3  | -0.3 | 2662 | Slightly Saline | 5229 | 7.2  | 29.9 | 31 |
| SG  | 2   | 0.8  | 1.2  | 1046 | Slightly Saline | 2013 | 7.2  | 28.2 | 29.5 |
|     |     | 2    | 0    | 1128 | Slightly Saline | 2158 | 7.4  | 28.1 | 29.6 |
| SG  | 3   | 1.57 | 1.43 | 2840 | Slightly Saline | 5655 | 7.3  | 29  | 29.9 |
|     |     | 0.87 | 1.13 | 940  | Fresh Water     | 1890 | 7.3  | 29.4 | 31 |
| SG  | 2   | 2.82 | -0.82| 1370 | Slightly Saline | 2730 | 7.3  | 30  | 32.5 |
|     |     | 0.63 | 1.37 | 1630 | Slightly Saline | 3260 | 7.3  | 28.4 | 29.6 |
| SG  | 2   | 1.35 | 0.65 | 1700 | Slightly Saline | 3370 | 7.3  | 28.6 | 30.7 |
|     |     | 2.10 | -0.1 | 2050 | Slightly Saline | 4080 | 7.3  | 28.9 | 31.2 |
| SG  | 2   | 0.79 | 1.21 | 520  | Fresh Water     | 1050 | 7.4  | 27.7 | 30.3 |
|     |     | 1.4  | 0.6  | 630  | Fresh Water     | 1270 | 7.6  | 28.5 | 30.3 |
| SG  | 2   | 0.85 | 1.15 | 650  | Fresh Water     | 1310 | 7   | 29  | 33.3 |
|     |     | 1.70 | 0.3  | 640  | Fresh Water     | 1300 | 7.1  | 29  | 33.3 |
| SG  | 2   | 3.70 | -1.7 | 620  | Fresh Water     | 1320 | 7.1  | 29.6 | 33.3 |
|     |     | 1.13 | 0.87 | 1590 | Slightly Saline | 3170 | 7.1  | 28.5 | 33.5 |
| SG  | 2   | 2.50 | -0.5 | 3580 | Moderately Saline | 7050 | 7.1  | 28.7 | 33.5 |
|     |     | 0.45 | 1.55 | 2150 | Slightly Saline | 4380 | 7.3  | 28.6 | 33.2 |
| SG  | 2   | 1.10 | 0.9  | 2280 | Slightly Saline | 4590 | 7.5  | 29.0 | 33.2 |
|     |     | 0.30 | 1.7  | 1050 | Slightly Saline | 2110 | 7.2  | 29  | 33.2 |
| SG  | 2   | 1.30 | 0.7  | 1130 | Slightly Saline | 2250 | 7.4  | 29.2 | 33.2 |
|     |     | 0.43 | 1.57 | 2270 | Slightly Saline | 4553 | 7.3  | 28.6 | 33 |
| SG  | 2   | 1.5  | 0.5  | 3271 | Moderately Saline | 6607 | 7.5  | 29  | 33.1 |
|     |     | 0.36 | 1.64 | 2178 | Slightly Saline | 4305 | 7.3  | 28.7 | 33.4 |
| SG  | 2   | 1.74 | 0.26 | 3446 | Moderately Saline | 7001 | 7.4  | 29  | 33.3 |
|     |     | 0.92 | 1.08 | 1997 | Slightly Saline | 4037 | 7.1  | 28.6 | 30 |
| SG  | 2   | 2.2  | -0.2 | 3198 | Moderately Saline | 6500 | 7.3  | 29  | 32.3 |
|     |     | 0.75 | 1.25 | 1255 | Slightly Saline | 2600 | 7.1  | 28.4 | 29.5 |
| SG  | 2   | 2.34 | 0.34 | 1980 | Slightly Saline | 3799 | 7.1  | 29.3 | 30 |
Based on iso-phreatic map of the research area the direction of dominant groundwater flow is leads to the sea. But there are some reversals in the direction of groundwater flow as at the point of SG 12 where the groundwater level at this point is lower than the surrounding area, so that the groundwater flow around it again leads to that point. In the reconstruction of the cross-section it is seen that the water level of the river (surface water) is lower than the groundwater level, indicating that the ground water fills the river or river water is effluent.

3.3. Groundwater Physical Properties

3.3.1 Temperature. The measurement of groundwater temperature is carried out at 3 depths. In each depth we get the ground water temperature data as follows:
- At ± 1 masl groundwater temperature range between 27.7 °C to 29.4 °C.
- At ± 0 masl groundwater temperature range between 28.1 °C to 29.9 °C.
- At ± 1 masl groundwater temperature range between 29 °C to 30 °C.

Based on the data can be deduced that the deeper groundwater have the higher temperature.

3.3.2 pH. The measurement of groundwater pH is carried out at 3 depths. In each depth we get the ground water pH data as follows:
- At ± 1 masl groundwater pH range between 7 to 7.4, the lowest pH is on SG 11 and the highest pH is on SG 10
- At ± 0 masl groundwater pH range between 7.1 to 7.5, the lowest pH is on SG 11, SG 3 and SG 18 and the highest pH is on SG 15
- At ± -1 masl groundwater pH range between 7.1 to 7.3, the lowest pH is on SG 11 and the highest pH is on SG 6

Based on the data can be deduced that the deeper groundwater have the higher pH (more alkaline).

3.3.3 TDS. The measurement of groundwater TDS is carried out at 3 depths. In each depth we get the ground water TDS data as follows:
At ± 1 masl groundwater TDS range between 520 to 3409 mg/l the lowest TDS is on SG 10 and the highest TDS is on SG 2.

At ± 0 masl groundwater TDS range between 640 to 3505 mg/l the lowest TDS is on SG 11 and the highest TDS is on SG 2.

At ± -1 masl groundwater TDS range between 640 to 3580 mg/l the lowest TDS is on SG 11 and the highest TDS is on SG 12.

Based on the data can be deduced that the deeper groundwater have the higher TDS (interpreted to contain more salt).

3.3.4 EC. The measurement of groundwater EC is carried out at 3 depths. In each depth we get the groundwater EC data as follows:

At ± 1 masl groundwater pH range between 1050 to 6753 μS/cm the lowest EC is on SG 10 and the highest EC is on SG 2.

At ± 0 masl groundwater EC range between 1300 to 7003 μS/cm the lowest EC is on SG 11 and the highest EC is on SG 2.

At ± -1 masl groundwater EC range between 1320 to 7050 μS/cm the lowest EC is on SG 11 and the highest EC is on SG 12.

Based on the data can be deduced that the deeper groundwater have the higher EC (interpreted to contain more salt).

4. Discussion

Based on the iso-phreatic map of the study area it is known that the dominant groundwater flow direction leads to the sea, however there are some points where the groundwater level is lower than the surrounding area, so that the direction of groundwater flow of the surrounding area reverses to that point, as happened at point SG 12, SG 13, and SG 15. Based on the correlation of flow direction data and the distribution of physical properties of groundwater in the study area, it is known that the river water surface water is lower than the groundwater surface level. This shows that the river is effluent to the groundwater. Points that have lower groundwater surface level such as SG 12, SG13, SG 15 and SG 2 have higher TDS and EC values compared to the surrounding area, it is also a sign that at that point there has been a groundwater excessive pumping that causing the equilibrium between freshwater and salt water undisturbed and eventually forming a new equilibrium zone that forms a brine cone against fresh water. This phenomenon is usually referred to as upcoming. Based on TDS data the research area is divided into 3 intrusion zones according to groundwater salinity based on TDS value compiled by Davis and De Wiest, 1996 with high intruded based on the value of EC. The determination of the intrusion zone in the study area is based on the following iso-TDS and iso-EC in figure 2 and figure 3.

Maps in figure 2 and figure 3 display the iso-TDS and iso-EC lines at groundwater level of 1 masl. Based on the lines connecting the distribution of data it is show that the strongest intrusion is in the northern part of the research area, which is the area closest to the sea. At a depth of 0 mdpl the zone extends to the south part of research area with the worst intrusion level at the point of SG 12, where the TDS value reaches 3580 mg/l at a depth of 0.5 meters below sea level and the EC value reaches 7050 μS/cm at the same point. As for the points classified as freshwater zone did not change significantly, the change in TDS value at SG10 point was from 520mg/l at depth of 1.21 meters above sea level changed to 620 mg/l at depth of 1.3 below sea level. And for the DHL value changed from 1050 μS/cm to 1320 μS/cm at the same points.
Based on the correlation between iso-phreatic map and groundwater physical properties, there are 3 zone of groundwater intrusion on the research area.

- **Zone I**: Moderately Saline High Intruded Zone, which occupies the northern part of the research area. This zone is the zone with the worst intrusion rate with the TDS value reaching 3580 mg/l at a depth of 0.5 meters below sea level and the EC value reaches 7050 μS/cm at the same point.

- **Zone II**: Slightly Saline High Intruded Zone, which occupies the middle to the south of the research area. This zone is a zone with an intrusion rate that is the average in the study area, in other words most of the study area is grouped in this zone. This zone has a range of TDS values of 1000-3000 mg/l and EC value range of 2000-5000 μS/cm.

- **Zone III**: Freshwater High Intruded Zone, which occupies the western and eastern part of the research area. This zone is a zone with a normal groundwater condition in the study area. Grouped as freshwater based on the value of TDS below 1000 mg/l, and high intruded based on EC value which is below 2000 μS/cm. On point SG11 the value of TDS at depth of 1.3 meter below sea level is 620 mg/l and the value of EC is 1320 μS/cm at the same point.
Based on natural factors, the influence of sea water intrusion is related to the distance from the coast and the depth of groundwater [5]. The closer to the shore the higher the intrusion of sea water that occurs and the deeper the groundwater the stronger the influence of sea water intrusion occurs. Whereas due to external factors (human activity) sea water intrusion is related to ground water retrieval. Excessive groundwater exploitation can lead to sea water intrusion [6].

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