MONITORING THE SEAWATER INTRUSION INTO COASTAL-AQUIFER USING GEO-ELECTRICAL SOUNING
A case study of the Northern-coastal area of Central Java, Indonesia

By
Sameer Simorangkir

ABSTRACT

The aims of this study are: (1) to investigate whether there is seawater intrusion into the coastal-aquifer of the northern-coast of Central Java, (2) to study the seawater intrusion movement along the corresponding coastal area, particularly from the district of Brebes to the district of Kendal.

To achieve the above goals, geo-electrical sounding technique was applied, hence by producing cross-sections of resistivity values which are perpendicular to the coast-line. The measurements were conducted in 1989 and 1996, each of which included eleven locations which were at the same spot. Resistivity shown in the cross-section is the resistivity of the rock composition and sea water in the aquifer. In this case, saline water has resistivity less than 1 ohm meter.

The result shows that in 1989, among the eleven measured locations, there was only one location indicated interface between fresh water and saline seawater. This was at the cross section number 5 obtained in Demak. In 1996, there were 6 locations indicated the occurrence of interface. Connect saline water was detected at every cross section with various depths.

INTRODUCTION

Coastal aquifer comes in contact with ocean at or seaward of the coastline and here, under natural conditions, fresh groundwater is discharged into the ocean. With increased demand for groundwater in many coastal areas, however, the seaward flow of groundwater has been decreased or even reversed, causing sea water to encroach and to penetrate inland in aquifers. This phenomenon is referred to sea water intrusion (Todd, 1959, pp.277).

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An interface is able to move toward the land when the hydrostatic pressure of the fresh water decreases. The decreased hydrostatic pressure of the fresh water is caused by the reduced amount of the groundwater resulting from several reasons. It can be due to the increase use of groundwater by people or due to lowering recharge of the aquifer caused by increase of area covered by an impervious structure over the recharge area of the corresponding aquifer.

The depth of an interface can be estimated by two approaches, i.e., by applying the Ouyama-Hirabayashi formula and by conducting the geo-electrical sounding survey. The Ouyama-Hirabayashi formula is written as:

$$h_i = 40 \times \frac{h_s}{h_f}$$  \hspace{1cm} (Wannielista, 1997) \hspace{1cm} (1)

where $h_s$ is the height difference between the sea surface level and the interface while $h_f$ is the height difference between the fresh water level and the seawater level (see Figure 1). The value of 40 was obtained by calculating the density of seawater and the density of the fresh water written as:

$$h_s = \frac{\rho_f - \rho_s}{\rho_f}$$  \hspace{1cm} (Wannielista, 1997) \hspace{1cm} (2)

where $\rho_f$ is the density of the fresh water ($\approx 1000$) while $\rho_s$ is the density of the seawater ($\approx 1025$). The values were obtained by measuring the samples of the fresh water and seawater in laboratory.

![Figure 1. Illustration of saltwater intrusion (Wannielista, 1997)](image-url)
Using the geo-electrical sounding technique, one may identify the stratigraphy of the resistivity of the rock separating the aquifer and the water inside. As an illustration, a rock containing water shows resistivity value less than the rock which has no water contain. Another example is a rock containing saline water which shows resistivity value less than that of the rock containing fresh water.

People often find saline groundwater in certain place and certain depth over the area, thus it is interesting and important to study the seawater intrusion phenomenon over the northern coastal area of the Central Java as. Kleiterman (1989) found the saline groundwater in this area is partly due to the existence of brackish water or saline water. Brackish water is seawater which was trapped during the formation of aquifer in the past.

Because of expansion of residential area, there has been increasing activity of groundwater pumping for domestic use. In addition, many fish/shrimp ponds which are built over the above-mentioned coastal area, have been pumping the groundwater extensively in order to supply the need of fresh water for their fish ponds. It is important to study whether the intrusion has any relationship with these pumping activities.

These facts stimulate a thought that the more groundwater over this area being pumped the higher possibility of intrusion will be. Likewise, the intrusion will be propagating further toward the land indicated by the shallower interface.

RATIONALES FOR THE STUDY

The increasing use of groundwater by fish/shrimp ponds located over the northern coastal area of Central Java may cause further propagation of seawater intrusion toward the land. It is, therefore, important to monitor the movement of the interface toward the land.

The geo-electrical sounding technique can be used to estimate the interface and to detect the locations of layers containing saline water. If the measurements were conducted in a certain period then the movement of the intrusion can be detected.

AIMS OF THE STUDY

The aims of the study are as follow:

1. to investigate whether the saline groundwater in the northern coastal area of Central Java is caused by the seawater intrusion or saline water occurrence.
2. to study whether the interface over this area is steady or moves from time to time.

THEORETICAL BACKGROUND

Hydrostatic pressure of the groundwater prevents the saline seawater for coming inland. This is the case when the hydrostatic pressure of the groundwater is higher than that of the seawater. When the hydrostatic pressure of the groundwater is getting lower, the seawater can move further inland (Todd, 1959).
The decline of such hydrostatic pressure is commonly due to the intensifying use of the groundwater. The groundwater use increase because of several reasons such as the increase of domestic use and industrial one as well. The intensification of groundwater pumping activity in many fish ponds, in particular, has been thought to cause the occurrence of seawater intrusion.

An aquifer containing saline water has resistivity value which is smaller than the resistivity of an aquifer containing fresh water. Zohdy’s (1980) study in the coast of California, showed that a saturated aquifer has resistivity values according to the type of material composition. The resistivity of sand and gravel saturated with fresh water ranges from about 15 to 600 Ohm meter. Field experience indicates the values ranging from 15 to 20 Ohm meter are characteristic of aquifer in the South Western United States, whereas for certain areas in California the resistivity of fresh water-bearing sand generally ranges from 100 to 250 Ohm meter. In parts of Maryland, resistivities have been found ranging from 300 and 600 Ohm meter. In California, it was found that the resistivity of an aquifer containing saline water was 10 Ohm meter.

A study conducted in Cisacap coastal area by Simon et al. (1976), indicated that the layer containing saline water has a resistivity of less than 2 Ohm meter. It was also found that the fresh water in Cisacap area lied on top of the interface of the Pemningen and the interface of the Damar River on the other side of Peninsula of Cisacap.

Simon (1996) conducted a groundwater study in the Pajur District of East Kalimantan Province. The aquifer over this area is composed of quartz-sand material. It was found that the saturated aquifer containing fresh water has resistivity ranging from 500 to 600 Ohm meter while the unsaturated aquifer has resistivity of more than 1500 Ohm meter.

Based on the theory and the results of several studies previously mentioned, it can be inferred that the geo-electrical sounding technique is useful in determining the depth of saline groundwater and in detecting any occurrence of interface in a given location.

**HYPOTHESIS**

Considering the theory mentioned earlier, there are two hypothesis can be made, i.e.

1. The geo-electrical sounding can be applied for determining the cause of saline groundwater in the northern coastal area of Central Java. Hence, whether it is caused by seawater intrusion or it is caused by the existence of saline water.
2. The movement of sea water intrusion toward the land is related to the pumping activities conducted by fish/shrimp ponds.

**METHODS**

The geo-electrical sounding technique applied in this study was the Schlumberger method. The alternating current (AC) was obtained from a 500 watt Honda generator which was then transformed into a direct current (DC) with a potential
of 220 - 440 Volt. This electrical current was introduced into the ground via two current electrodes (A and B). The change in potential induced by the electrical current was measured using two potential electrodes (M and N) after passing a compensator. This compensator was necessary for eliminating spontaneous potential from the ground. The electrical current (I) and the potential difference (UV) were measured using two digital multimeters.

The array of the electrodes in the Schlumberger method is as follows: L/2 (half A-B) is always the same or higher than \( \frac{a}{2} \) (half M-N). In another words, AB \( \geq \) 5MN. The extent of the current electrodes (L/2) was 250 meters, thus the depth that can be estimated was L/2 (insets).

The resistivity is calculated using the formula written as:

\[
\rho = \frac{\Delta V}{I}
\]

(Zobaly, 1980) (3)

where

\( \rho \) = apparent resistivity (in ohm meter)

\( C \) = a constant which depends on the extent and the array of the electrodes. Here,

\[
C = 2\pi (\frac{1}{AN - AM - BN - BM})
\]

\( \Delta V \) = potential difference (millivolt)

I = electrical current which was introduced to the ground (milliamper).

The array of the electrodes in the Schlumberger’s method is illustrated in Figure 2.

![Diagram of a geoelectrical sounding with a Schlumberger array](image)

*Figure 2. Geoelectrical sounding with a Schlumberger array (after Todd, 1989)*
Figure 3. An example of interpretation using the Schlumberger O'Neill program. The interpretation shows the resistivity and the depth of each layer.
The geo-electrical sounding data, i.e. L2 and resistivity \( p_h \) obtained from the field were put into a Schlumberger Orchi computer program. Interpretation was then conducted to obtain resistivity values (namely \( p_1, p_2, p_3 \) and so on) as well as the depth of each layer. An example of the interpretation result is provided in Figure 3.

In Figure 3, the Y-axis is the resistivity while the X-axis is the depth. Symbol (+) shows the measured resistivity value while symbol (—) shows the applied standard curve. The solid line indicates the result of the interpretation. In order to obtain resistivity profile of the coast toward the land, the soundings were performed in two to three points. By doing so, a cross-section is produced by interpolating one to another point.

The field work was conducted in 1989 and in 1996. According to the former plan, monitoring will be conducted in the year of 2001, but until May 2001 there is no sponsor yet. There is also a plan of a student of the Faculty who will take this matter for his thesis.

Both the 1989 and 1996 field works were conducted over the northern coastal area of the Central Java Province, i.e. from Brecos to Rembang. In the future, the monitoring will only be performed in the area covering Brecos to Kendal.

In this paper, the focus is placed upon the result of geo-electrical sounding over Brecos to Kendal (see Fig.4). There are 11 cross-sections to be discussed (see Appendix). A resistivity of less than 1 ohm meter is found in the cross-section, while this cross-section is separated from sea-salt water, then the ground-salt water is not brought by the sea water intrusion but is caused by the connate water. It also can be informed that ground water samples taken from these areas by the students of the Faculty of Geography, Gadjah Mada University and the students of the Free University, Amsterdam, show that the water is contained in the rock for such a long time (Klimkiewicz, 1989).

**RESULTS**

Initially, both the 1989 and 1996 field works were not specifically conducted for seawater intrusion monitoring purposes. Actually there were more than 20 sounding points with different locations (but they cannot be used for monitoring purposes).

Among these, eleven points were chosen for monitoring purposes due to the fact that they were located at the same locations (or relatively close) both in the 1989 and 1996 sounding. Hereinafter the cross-sections is called cross-section PU1, PU2, ... PU11 where PU is an abbreviation of Panjaitan Ulah with a southern coast. The file name is PU 01-01, PU 01-02 and so on. The location, including the name of the village and the UTM grid of each sounding is provided in Table 1.
<table>
<thead>
<tr>
<th>Year</th>
<th>Name of Village</th>
<th>UTM grid</th>
<th>Depth of Irrigation (m)</th>
<th>Name of Village</th>
<th>UTM grid</th>
<th>Depth of Irrigation (m)</th>
<th>District</th>
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<td>Lumi Kiddi village</td>
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<td>120</td>
<td>Karunggung</td>
<td>82752-254</td>
<td>180</td>
<td>Betania</td>
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<td>Karunggung</td>
<td>82752-254</td>
<td>180</td>
<td>Betania</td>
</tr>
</tbody>
</table>

Table 1: Detail information about the locations where geo-electrical sounding was performed as well as the depth of the interface in 1966 and 1970.
Cross-section number 1 (Pu1)
This cross-section is located in Brebes district. In 1989, there were three locations (Losari, Kedungsoedeng, and Bahadin) while in 1996 there were only two locations (Losari and Kedungsoedeng). In 1989 there was no interface detected. On the contrary, in 1996 in the Losari site there was an interface detected at the depth of 120 m.

Cross-section number 2 (Pu2)
This cross-section is located in Brebes district. In 1989, there were three sounding points (Bubakanama, Baluran and Rancawulan) and no interface was detected. In 1996, there were also three measurement points (Pulas Gading, Pakijangan and no name). At Pulas Gading which is closest to the Bulakanama, an interface at the depth of 95 m was observed.

Cross-section number 3 (Pu3)
This cross-section is in Brebes district. In 1989, there were three sounding points (Tegaluni, Debang and Pagungan). At that time, there was no interface detected. In 1996, there were two sounding points (Kenton Lor and Debang) and no interface was detected.

Cross-section number 4 (Pu4)
This cross-section is located in Tegal district. In 1989 there were three sounding points, i.e. at Sarududi, Bulakan and Penang Jati. Interface did not exist. In 1996, there were two sounding points, i.e. at Sarududi and Bulakbangting. Interface was not detected.

Cross-section number 5 (Pu5)
This cross-section is in Pemulang district. In 1989, there were three sounding points, i.e. at Badur, Nanjarayy and Kendayan. Interface was observed at the depth of 160 m. In 1995, there were two sounding points, i.e. at Badur and Banjarayy. The interface found in Badur and Banjarayy was at the depth of 150 m and 150 m respectively.

Cross-section number 6 (Pu6)
This cross-section is in Pemulang district. In 1989, there were three locations i.e. Klarean, Bulu and Senua, there was no interface detected. In 1996, there were two points i.e. at Klarean and Bulu. An interface was detected at Klarean at the depth of 80 m.

Cross-section number 7 (Pu7)
This cross-section is in Pekalongan district. In 1989, there were four locations (Api-api, Mogaya, Kastil and Kudipaten Kuda), interface had not been detected. In 1996, there were two sounding points i.e. Rancawatan (next to Api-api) and Pakonson. An interface was detected at Rancawatan at the depth of 110 m.
Cross-section number 8 (PU8)

This cross-section is in Pekalongan district. In 1989 there were three locations i.e. Runcu, Panjang Kilomet and Telaga. There was no interface observed. In 1995, there were two locations (Kramprakor and Krampiing) where there was no interface detected.

Cross-section number 9 (PU9)

This cross-section is in Botang district. In 1989, there were three sounding points (Kragungati, Peajakramin and Stinginari) while in 1996 there were two locations (Kragungati and Botang). In both years, there was no interface observed.

Cross-section number 10 (PU10)

This cross-section is in Kendal district. In 1989, there were two locations (Sidang and Krangkang) and no interface was detected. In 1995, there were two locations i.e. at Sonang and Compol Sari. An interface was observed at Sonang at the depth of 58 m.

Cross-section number 11 (PU11)

This cross-section is in Kendal district. In 1989, there were three sounding points (Betaksudaung, Stebbong and Salatone) while in 1996 there were two locations (Betaksudang and Katinggari). There was not any interface detected in both years.

DISCUSSIONS

Taking the band use surrounding each cross section into consideration, the discussion of the results of each cross section can be given as follows.

Cross section number 1 (PU1)

This location is an extensive and a wide fish pond area where most of the fish companies pump the groundwater in order to fulfill their fish pond needs. Additionally, this is a developed residential area due to its position which is at the intersection of an alternative road (singap, Losari), i.e. in the direction to Parowidobo.

In Losari (UTM grid of 92142-2583), there was no interface in 1989. On the contrary, in 1996 there was an interface at the depth of 120 located at approximately 3.4 km of the coastline. It is suspected that the rise of each interface was triggered by the extensive pumping of the groundwater by the fish pond industry. This matter requires a further study for studying the relationship between the amount of groundwater being pumped and the increasing of an interface. In addition to the interface, seawater was detected at the depth of up to 20 meters was also found in Losari.

Cross section number 2 (PU2)

Both Bulalahang (UTM grid 92400-2725) in 1989 and Pakjangan (UTM grid 92404-2746) in 1996 showed no interface. At the same time, however, in Palanggang (UTM grid 92028-2731), a wide fish pond area, there was an interface observed at the depth of 95 meter at around 500 m from the coastline.
In addition to the interface, connate saline water was also detected at each sounding point, thus at all the cross section and the surrounding area. The depth of the connate water ranges from 5 to 20 meters with a thickness ranging from 15 to 30 meters.

Cross section number 3 (PUS)
This section is located at an urban area and partly crosses the fishpond area. Both soundings performed in 1989 and 1996 showed no interface. In Kanto Lee (UTM grid 924128-2924) the occurrence of connate saline water at the depth ranging from 5 to 20 meters was detected. In Degeben (UTM grid 92377-2927) the connate saline water was observed at the depth of 10 to 20 meters.

In this location, there are three rivers running so close to each other, i.e. Vahagali, Gang, and Wadas River. Although no interface is detected, there are connate saline water lens at the depth ranging from 5 to 25 meters.

Cross section number 4 (PUS)
In this location, there is no fish pond and the residential area is relatively small. It is not surprising if there was no interface detected in both 1989 and 1996 field works. Geographically, this location lies on top of the Salagubang hill area so that the fresh groundwater runs from a wide recharge area. In the Saboddhi to Biukka area, connate saline water was found at depth of 40 meters.

Cross section number 5 (PUS)
In this location, the residential area and fish pond is quite small. The groundwater is not yet pumped to fulfill the need for fish pond. In Badar (UTM grid 92309-2041), in 1989 the interface was found at the depth of 160 meters while in 1996 the interface was getting shallower (i.e. at 150 meters). The connate saline water was also detected in Badar at 10 meters depth.

In Tungnarom (UTM grid 92553-3296), an interface did not exist in 1989. However, in 1996 an interface was detected at the depth of 160 meters. This is presumably caused by the extensive use of the groundwater.

Cross section number 6 (PUS)
This location is characterized by a big fish pond where ground water is extensively used. In Klarano (UTM grid 92429-3306), no interface was detected in 1989. In 1996, an interface was observed at the depth of 80 meters. Since the groundwater used for residential and industrial areas are relatively zero in this area, such interface may be due to the use of groundwater for the fish pond. In Klarenos, there was also connate saline water at the depth of 10 to 40 meters.

Cross section number 7 (PUS)
A large fish pond and a small residential area are the feature of this location. In Radonwat (UTM grid 92400-3419) no interface was found in 1989. In 1996, an interface was found at 100 meters. The existence of such interface, therefore, is caused from the excessive pumping of the groundwater for fulfilling the need of the fish pond.
In addition to the interface, connate saline water was also observed at the depth ranging from 5 to 60 meters.

Cross section number 8 (PU7)
There is no fish pond at this location. Likewise, there was no interface detected. Connate saline water lens was observed at the depth ranging from 5 to 25 meters.

Cross section number 9 (PU9)
No interface was detected in both 1989 and 1996. This area, where the city of Butuan is located, has no fish pond. Hence, the domestic and industrial uses of the ground water do not largely influence the seawater intrusion. Small connate saline water lens at the depth up to 16 meters were noticed in Kanganui (UTM grid 92390-5610).

Cross section number 10 (PU10)
Although fish pond in this area is small, the company used the groundwater intensively. In Sendong (UTM grid 92360-3962) there was an interface (58 meters) in 1996 but none in 1989. This interface is presumably not only due to the intensive use of groundwater but also due to the small recharge area (i.e. ±9 km) from the shoreline. In addition to the seawater intrusion, connate saline water was also observed (10-40 meters) in the area of Sendong to Gempolbakan.

Cross section number 11 (PU11)
This location has a large fish pond and it is situated at the tidal flat so that the seawater enters the fish pond easily. There is no need to pump the groundwater for the fish pond. Here, interface was not detected in both 1989 and 1996. In Betahamang (UTM grid 52364-4124) connate saline water was also observed at the depth between 5 to 30 meters. Its lens was observed up to Sukodone (UTM grid 92123-4119) with the depth of 5 to 20 meters.

CONCLUSIONS
Based on the discussion provided previously, it can be concluded that:
1. connate saline water was detected at every cross section at various depth. This is why some people find that their wells contain saline water.
2. there is a movement of seawater intrusion toward the land. This is marked by the existence of interface which was not observed before at the decreasing depth of the interface in 1996 (compared to the depth in 1989). It is also noticed that the existence of interface associate with the increasing amount of groundwater pumping for fish pond.
3. Interface movement can be monitored using the geo-electrical sounding technique.
SUGGESTIONS

It is important to monitor at least every 5 years the intrusion using the geo-electrical sounding technique, particularly over the area where the fish pond pumps the groundwater extensively. It is also important to study the relationship between the amount of groundwater being pumped and the increasing level of the interface.

REFERENCE


Location of Cross Section PU-4 and PU-5
Location of Cross Section PU-8
Location of Cross Section PU-9
Location of Cross Section PU-10
Location of Cross Section PU-11