Subsurface investigation of seawater intrusion and its impact to the domestic water fulfillment in Pekalongan City, Indonesia

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Abstract. The increasing of population growth in the Coastal Area of Pekalongan City has caused serious problem to the domestic water supply. It was getting worst due to seawater intrusion phenomenon. This research aims to investigate seawater intrusion using geophysical method and observe its impact to the domestic water fulfillment. Three sections of 2D resistivity were run approximately 250 meters'perpendicular from the coast line. The resistivity data were processed using RES2DINV software. We also did aninterview to 90 householdsto find out the impact of seawater intrusion in domestic water usage. The result showed that seawater has intruded up to 800 meters from the coast (represent with very low resistivity, <5 Ωm) and increased groundwater salinity significantly to a depth of 13 meters.Nearly everyhousehold in the North part of Pekalongan City could not use groundwater to fulfill their domestic neededdue to the massive seawatercontamination. They had a big dependency of water supply from the government drinking water company even with poor quality. Preventive mitigation action is really urgent to be done in order to reduce the future risk of seawater intrusion in the coastal area.

1. Introduction

Pekalongan is amedium city located in the North Java coastal area(figure 1). The population was increasingly growingsince it passed by the main transportation tract which connects some big citiesaround Java. In addition, the development of textile industriesalso gives impact to the growth of build area. During 2000 until 2015, the population growthrecorded at 7.3% and it is predicted to be increasing continually with up to 9, 45% in 2035 [1]. The consumption of water must be increase along with the population growth phenomena in the coastal area.

Physically, PekalonganCity develops in area with abundant groundwater resources, because it is located in a flat coastal area composed by loose material. In the past,many people used shallow groundwater to fulfill their domestic needs. They could gain fresh water by just dug a well in less than 3 meters' depth. Whereas, during ten years ago they wereforced to bury their wells because the water become brackish to salty.This phenomenon shows an indication of seawater intrusion that very vulnerable happen in coastal area [2].

Many researchers have conducted electrical conductivity measurement on several wells to identify the occurrence of seawater intrusion. A study discovered that most wells in the Pekalongan coastal area had electrical conductivity up to1.500 μS/cm – 2.200 μS/cm or categorized as brackish to saline water[3]. In 2017, by using the same method, there was an indication of intruded seawater up to 600 meters from the coastland in certain areas [1].Most of studiesin the study area only focused on the surface measurement by investigate the electrical conductivity of wells, but still there is no study about the subsurface yet. We are urged to have a deeper subsurface investigation to findthe recent condition of seawater intrusion in that area.

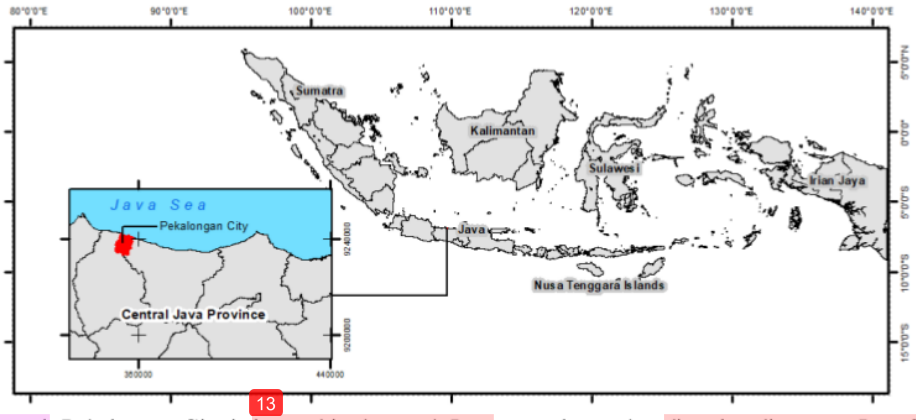

Figure 1. Pekalongan City is located in the north Java coastal area that directly adjacent to Java Sea.

The result of subsurface investigation will be very accurate if we use drilling or coring methods, but it will consume so much time, money and effort [4][5]. Geophysics approach could be a better option to gain a faster, cheaper and easier subsurface interpretation. One of the geophysical approaches that has been widely used in various countries for seawater investigation is geoelectric method [6][7][8]. This method is very suitable because electrical parametershave a high sensitivity on salinity contain.The higher level of water salinity, the lower level of electrical resistivity, so that either seawater or groundwater could be easier to be differentiated because they have huge disparity on salinity contain [9]. The aims of this research are to investigate seawater intrusion using geoelectric methods and observe its impact to the water domestic fulfillment to the society in the Pekalongan coastal area. Two dimension (2D) resistivity method was designed to have spatial profile both horizontally and vertically.The annual Monitoring of seawater intrusion is very essential to be done in order to reduce the risk in the future.

2. Methods

2.1. Geoelectric method

Electrical resistivity is an ability of material to obstruct the electrical current. The properties of material such as compactness, porosity, density, water content and salinity will contribute to the disparity of resistivity value. Resistivity measurement on field was conducted by giving electrical current injection into the ground from a pair of electrodes which then the total of potential differences across the medium will be obtained from another electrode pair. The total of electrical current (I), potential difference (V) and spacing of the configuration electrodes in each pair (κ) (formula 1)gained from the field will result the apparent resistivity (ρ_a) of material (formula 2). Then, true resistivity obtainedthrough a mathematics process called invers modelling using RES2DIVN software. In this research, three lines of 2D resistivity profile were run perpendicular from the coastline. The distance of a is 10 meters, while the total of depth array (n) is 6as designed in figure 2.

$$\kappa = \pi n\ (n+1)\,(n+2)a \qquad (1)$$

$$\rho_a = \frac{V}{I}\kappa \qquad (2)$$

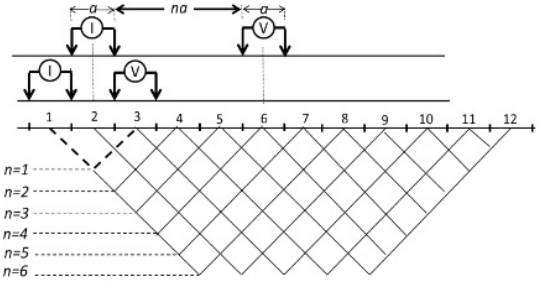

Figure 2.2D resistivity section designed with dipole-dipole configuration.

2.2. Social interview

A random sample of 90 households becamerespondentfor a large survey in order to gaininformation about the impact of seawater intrusion phenomena to their domestic water fulfillment. Data were collected randomly by interviewing households in Panjang Wetan sub-district and Kandangpanjang sub-district. The questionnaire contains some questions related to water quality of the wells, kinds of water resources used to fulfill their domestic needs, cost to get fresh water, and obstacles in fresh water supplying. The data interviews were processed and represented in the form of picture, graphic and table.

3. Results and Discussion

3.1. Subsurface investigation

2D resistivity model using RES2DINV software was represented in the form of blocks section. The length of line surveying determines the length of block section while the value of *a* and *n* will have impact on the depth of block section. The length of first, second, and third sections respectively are 190m, 250m, 140m, and all of them have 16,4 m in depth.

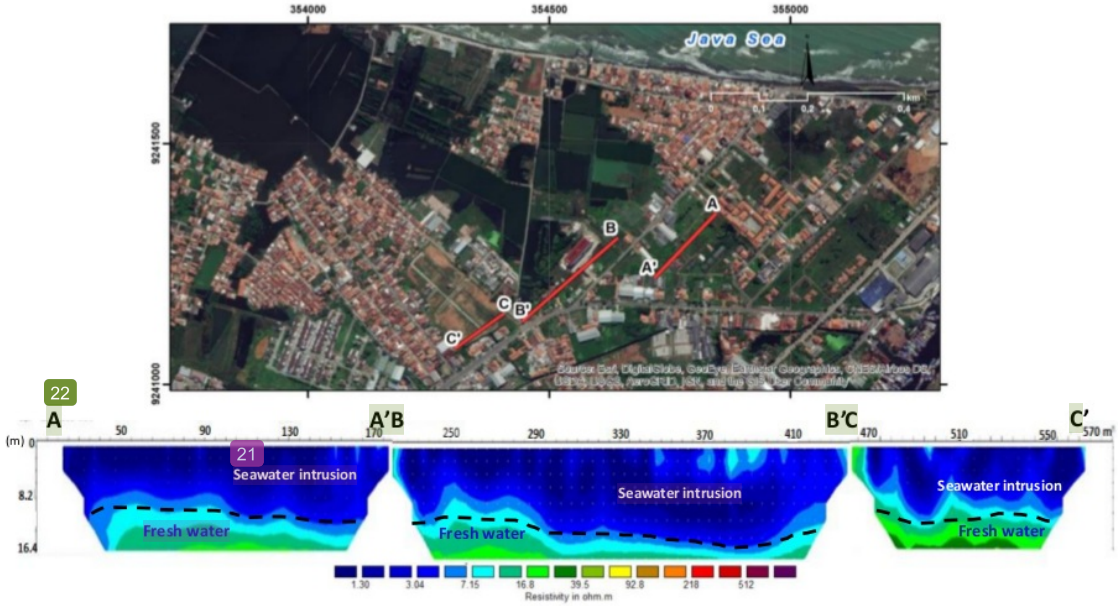

Figure 3. The result of 2D resistivity section discovered that the thickness of seawater intrusion (blue color) was 10 ~ 16 meters and the contamination has reach more than 1 kilometer from the coastline.

The three of 2D sections showed that there wasa same pattern of resistivity value under the surface. Very low resistivity (<5Ωm) was captured covering the top layer laterally and the resistivity value was getting bigger along with increasing in depth (10-40Ωm) (Figure 3). Very low resistivity located in the surface layer showed that seawater has contaminated the shallow groundwater in that area. Seawater has intruded until 10 meters under the surface, moreover it reached 16 meters in the second resistivity section. Based on the three 2D resistivity section, seawater intrusion has already reached almost 1 kilometer from the coast.

The result of subsurface investigation using 2D resistivity method showed a strong correlation with the water quality of several wells in the coastal area. Almost all wells along 1 kilometer from the coast has brackish to saline water. The groundwater level of wells is only about 1 until 2 meters beneath the surface. The fresh water starts to occur if people make a deeper well with up to 20 meters'depth from the surface, and it was also represented in the 2D section where the resistivity is increasing beneath more than 15 meters.

The water resistivity pattern along the coastal zone of Pekalongan city is quite unique and distinctive from the Sea-water Intrusion theory in the earlier studies, like the Coastal Italy [7] or in India [6]. Study of sea-water intrusion using 2D resistivity cross-sections surveys are generally has pattern on its resulting images where the top layer tends to have a higher resistivity value to represent the conditions of unsaturated soils in the upper layer, and saltwater may intrude into freshwater aquifers causing the underground layer to gain lower resistivity value. In the case of Pekalongan's coastal zone, it's quite difficult to distinguish the top layer and the aquifer that has been intruded by seawater, due to the similar respond they have on resistivity value. High salinity content is expected to be the cause of low resistivity value in the top layer, which leads to flooding that occurs frequently in the surrounding region of northern coast of java.

Figure 4. Interviewing households to ask the impact of seawater intrusion on the domestics needs.

Figure 5. one of the well that could not be able to use anymore because of seawater contamination.

3.2. Impact of seawater intrusion

Interviews with 90 respondents whose residing in a radius of less than 1 kilometer from the coastline of north Pekalongan sub-district, revealed that the large part of communities were now unable to use the shallow aquifer for daily use due to the contamination of sea-water intrusion (figure 4). Shallow wells that could have been used for domestic necessity are currently become salty therefore need to be structurally stable and backfilled or sealed to prevent groundwater pollution and flow of water between different aquifer units. Most people eventually prefer to get water from their local water-supply company known as PDAM or pamsimas. The expenses incurred for each family range from Rp. 30.000,00 to Rp. 200.000,00, it depended on the number of the family members.

The seawater intrusion phenomenon is threatening the lowland area of the city. It damages or makes the water resources such as their wells unusable for local people that live in the north coast of Pekalongan (Figure 5). Most people are depending their water supply on PDAM. Unfortunately, not all water comes from PDAM have certain qualities, as 34% respondents claimed to suffer from insufficient and poor service of water delivered from PDAM (Figure 6). The valuations were based on the murky, unpleasant smells and often yellow-colored water hence they can't consume the water for drinking purposes. Most of the people had to buy water in gallons in order to fulfill their basic

necessity such as drinking and cooking. That way, they have to spend money from range Rp.50.000,00 to Rp. 160.000,00 per month for water useconsumptions.

Figure 6. The distribution of respondents who give opinion related to the quality of PDAM service in Panjang Wetan and Kandangpanjang sub-district of Pekalongan City.

On the other side, even the rest of the residents with preferable water qualities are not really satisfied with the provided services. As many as 59% respondents claimed to have faced various technical issues oftentimes, such as water stops flowing in a sudden or low water flows rate. In what follows, people had been forced to spend a lot of money for a single unit of water tank. Moreover, for the people who can't afford to buy a water tank, they usually ask their neighbors for water or to get them from public places like a gas station.

4. Conclusion

Groundwater contamination by seawater intrusion in the Pekalongan' coastal area has been worrying from years to years. Subsurface investigation using 2D resistivity method recovers that saline water has been mix together with fresh water until 10 to 16 meters from groundwater level and it comes to reach 1 kilometer from the coastline. Consequently, people who live in the radius 1 kilometer from coast are not be able to use their shallow groundwater. They have big dependency on water-supply company to fulfill their domestic needs. They have to pay every month even for unsatisfactory service due to poor quality of water supply. Subsurface investigation of seawater intrusion needs a further range from the coastline, in addition the impact to the society also must always be monitored in order to reduce a potentially bigger adverse effect in the future.

Acknowledgments
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