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3D RESISTIVITY IMAGING AND PRECIPITATION DATA TO PREDICT SEAWATER INTRUSION IN TANAH MAS INDONESIA

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ABSTRACT: The seawater intrusion into the shallow groundwater in Tanah Mas residential North Semarang was predict by 3D resistivity imaging and precipitation data. The seawater intrusion was investigated by resistivity survey which generated by multi-electrode system with sixteen electrodes configuration. Analysis of rainfall data will show how much the influence of groundwater pressure from rainfall in the study area to the saltwater interface. The result of precipitation data indicates very low medium rainfall, with 0.6 mm for October 126.1 mm for November. In October, the coastal aquifer will be so pressed by salt water that sea water intrusion penetrates into freshwater areas. In November, the coastal aquifers are recharged by precipitation and replenished water flowing to the sea then prevent saltwater from encroaching into the area of freshwater. The resistivity survey detected the presence of seawater intrusion because it has a small resistivity range between 0.120-0.980 Ωm at a depth about 13.5 m to 26.9 m. 3D resistivity images show the distribution of seawater intrusion in the Tanah Mas area in horizontal and vertical direction. The distribution of seawater intrusion has reached northern, eastern and southern part of Tanah Mas area.

Keywords: *Resistivity, Precipitation, Seawater, Intrusion*

1. INTRODUCTION

Groundwater is an important component of the environment that is continuously used to supply various human needs. The human growth, massive exploitation of groundwater, and the climate change have and will impact the level and quality of groundwater [1,2]. It has been shown that excessive exploitation of groundwater leads to seawater intrusion in coastal areas and affects the quality of groundwater aquifers [3].

In nature, the saltwater interface rarely remains stationary because of the addition or reduction of the amount of water. Precipitation or rainfall is the main source of natural recharge which contributes to the availability of groundwater resources. High rainfall makes the groundwater become full so that it will suppress the seawater and deepen the saltwater interface.

Seawater intrusion constitutes the main environmental problem facing coastal aquifers worldwide [4-6]. Seawater intrusion is a global problem, exacerbated by increasing freshwater demand in the coastal zone [7]. Because of that, management plan for coastal aquifers is important in order to understand the origin and distribution of saltwater [8].

Semarang is a big city in Indonesia located on one of the deltas in the world and experiences an important urban growth. This developing city has over exploitation of groundwater, saltwater intrusion, land subsidence, and coastal inundation due to rapid urban growth. As population growth and urban development in Semarang City increase, the water stress rises significantly on groundwater [9,10]. Tanah Mas area is a densely populated area located in the northern coastal city of Semarang. In this area, the exploitation of groundwater through production wells is quite high, that potential to produce the phenomenon of seawater intrusion. So that the groundwater conditions in this area need to be investigated more deeply to provide accurate information so that it can be handled appropriately.

In examining the thickness and dimensions of subsurface depositional structures, the procedure that can be carried out are information from geological research, drilling, and exploitation drill holes. However, these methods are expensive, time-consuming, and covers a large area. Using geophysical measurements is a more appropriate solution because it is cheaper, non-destructive and able to provide fairly accurate subsurface information [11]. For this reason, in many studies, Geophysical surveys can provide field data that supports geological correlations, even in sectors where there are no boreholes data. Indirect geophysical methods (such as electrical resistivity and VES surveys) produce continuous data on the target and its surroundings. This helps in studying the spatial relationship between freshwater, brackish water, and saltwater, which usually coexists in coastal aquifers.

Geoelectrical resistivity imaging has been used to examine various hydrological, environmental, and engineering problems [12-14]. The geoelectrical resistivity technique is a geophysical method that utilizes the resistivity properties of subsurface objects by inserting an artificial electric current into the ground through two electrodes and then measuring the potential field generated by the current with two other electrodes [15].

Based on the problem statements above, the investigation of seawater intrusion in Tanah Mas subsurface area is highly important to understanding its distribution. Geophysical survey will provide information on subsurface conditions. Then it is supported by rainfall data to determine the effect of groundwater pressure on saltwater interface. Depiction of subsurface models in 3D is an innovation that can show the pattern of target distribution in vertical and horizontal directions, not just depth profiles just like previous studies.

Based on previous research geoelectric methods were applied to monitor seawater intrusion in different parts of the world, see for examples: Sae-Ju et al. [16] Geophysical and Multivariate Statistical Investigation of the Seawater Intrusion in the Coastal Aquifer at Phetchaburi Province, Thailand, Fadili et al. [17] Geoelectrical And Hydrochemical Study for the Assessment of Seawater Intrusion Evolution in Coastal Aquifers of Oualidia, Morocco., Mogren [18] Saltwater Intrusion in Jizan Coastal Zone, Southwest Saudi Arabia, Inferred from Geoelectric Resistivity Survey, Rao et al. [19] Geophysical and Geochemical Approach for Seawater Intrusion Assessment in the Godavari Delta Basin, A.P., India, while Putranto et al. [20] Controlling Seawater Intrusion Beneath Semarang Coastal Urban City Using Geophysical Survey and Hydrogeochemistry Data.

2. DATA ACQUISITION

The rainfall data obtained in collaboration with Semarang Climatological Station. Rainfall observation stations used are adjacent to the research area that observation stations located at Tanjung Mas Semarang. Types of precipitation that will be observed are monthly rainfall data, rainy days, and maximum rainfall.

The geoelectric survey able to predict the subsurface resistivity pattern by making measurements on the topsoil. The subsurface resistivity is related to geological parameters such as the mineral content fluids, porosity, and saturation level of water inside rocks and soil [21]. The geoelectric survey was carried out during October and November 2015.

The geoelectrical lines with 150 m long were stretched up to obtain the optimum penetration depth. The main equipment used was the S-Field multichannel resistivity with a configuration of sixteen electrodes. Two software were used to process data and presented it in 2D and 3D profiles, namely RES2DINV and Rockwork in sequence.

The research location in the Tanah Mas area of Semarang (Fig.1). This location in the north of Semarang city. In the northern part is bordered by Java Sea and the western part is bordered by a river traversed the West Flood Canal. This location is developed starting in the late 1970s. Initially this area is an area of rice fields and then reclaimed and turned into housing. A phenomenon that occurs during the take 20 years is subsidence and groundwater level decline. The impact is the destruction of the environment, such as potholed roads, flood, salty well water in some places, the walls of buildings were destroyed, raising the floor of the house to cope with flooding that floor with a distance shorter roofs.

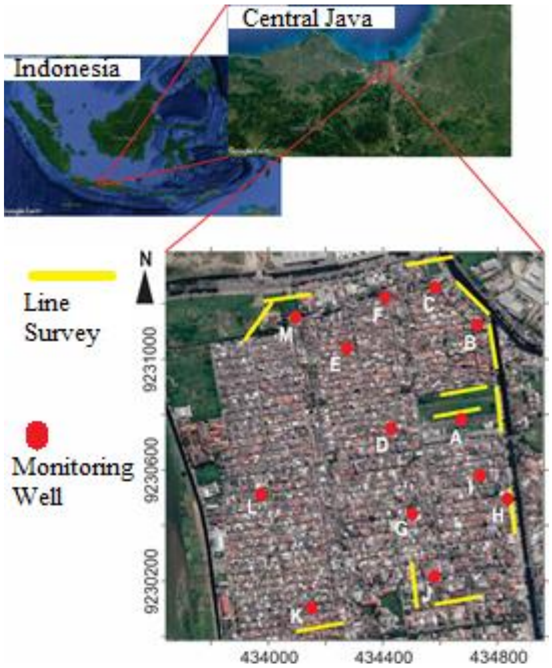


Fig.1 Location map (adopted from google maps)

3. RESULTS

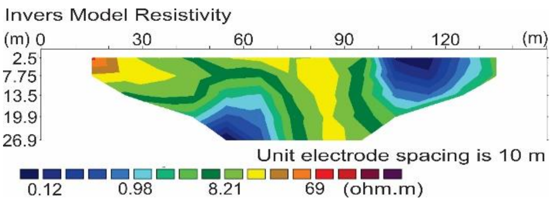
Resistivity and Precipitation data were carried out to examine the subsurface geologic formation and assessing seawater intrusion in Tanah Mas area of Semarang, Indonesia. Rainfall data (Table 1) was obtained from the Meteorological Climatology and Geophysical Agency (BMKG) Central Java Indonesia during 2015. The geoelectric measurements carried out in the same year. Distance to the study site with BMKG about 4 km, so that it can describe the recorded rainfall in the course of a study.

According to the table 1 daily rainfall can be classified into five, namely 1-20 mm/day (light rain), 20-50 mm/day (moderate rain), 50-100 mm/day (Heavy rain), >100 mm/day (Rainning very keavily), 0.0 (no rain), and monthly rainfall 1-100 mm (low), 101-300 mm (medium), 301-400 mm (high).

Table 1 Monthly Rainfall Data, Rainy Day, and Maximum Rainfall

Month	2015			
	Rainfall (mm)	Maximum Rainfall (mm)	Date Events	Number of Days Rain (day)
September	0.0	0.0	-	0
October	0.6	0.5	31	2
November	126.1	32.5	8	13
December	247.0	53.0	10	16

The resistivity acquisition has been conducted to predict the distribution pattern of seawater intrusion in Tanah Mas area. The subsurface images have been acquired across the study area using a multi-electrodes acquisition system in a sixteen electrodes configuration with spacing of 10 m for each line. The ten geoelectrical lines with 150 m long obtained same penetration depth of 26.9 m. Several of the 2D profiles obtained from lines located nearby wells shown in Fig.2.



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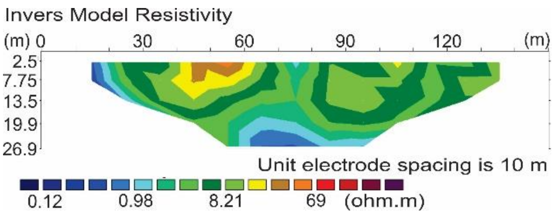

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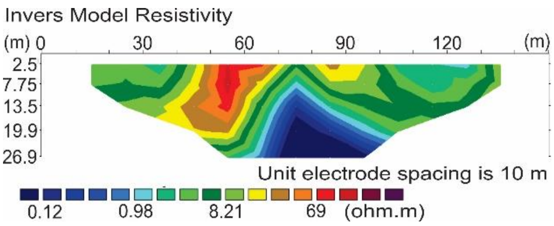
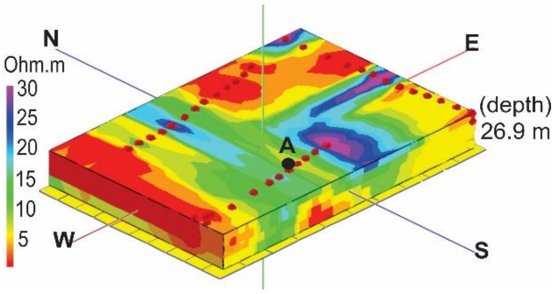


(c)

Fig.2 The 2D subsurface resistivity imaging of line located nearby (a) well A; (b) well B; (c) well J.

In 2D resistivity surveys, subsurface resistivity is usually assumed to vary vertically with depth and laterally along the profile, but constant in the direction perpendicular to the profile [14]. Then the 3D models were built from two or more 2D models using Rockwork software. The interpretation of 3D resistivity images where the resistivity values are allowed to vary in all the three directions, namely vertical, lateral and perpendicular directions gave a more accurate and reliable results [8].



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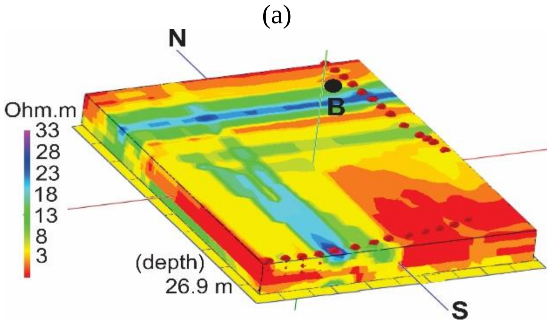

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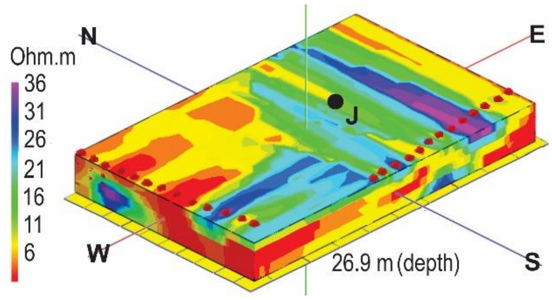


(c)

Fig.3 3D resistivity imaging from 2D resistivity imaging from lines located around (a) well A; (b) well B; (c) well J.

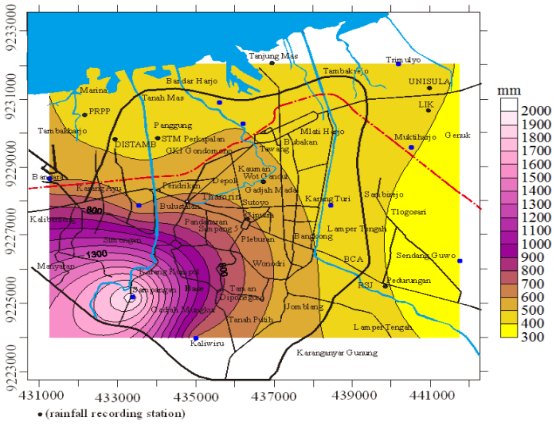
4. DISCUSSION

Changes in climatic factors, such as precipitation is very important parts of the hydrologic balance. In October the amount of rainfall is 0.6 mm, which indicates very low rainfall for the month. The number of rainy days intensity of 0.5 mm which occurred on October 31. In natural conditions, this coastal aquifer will be so pressed by salt water that sea water intrusion penetrates into freshwater areas. In November the amount of rainfall of 126.1 mm, which indicates medium rainfall for the month. The number of rainy days this month as many as 13 events with the highest rainfall intensity of 32.5 mm which occurred on November 8. Under natural conditions, these coastal aquifers are recharged by precipitation, and replenished water flowing to the sea will prevent saltwater from encroaching into the area of freshwater [22]. Rainfall in repelling the intrusion of seawater, which applies to a wide range of practical aquifer. The effect of non-uniform intensity of rainfall such as daily, weekly, and monthly average values do not show significant deviations from the average value of seasonality in terms of the overall reduction of intrusion achieved.

Fig.2 shows the image generated by RES2DINV software which represents the 2D subsurface resistivity imaging acquired from the line located nearby well A, B and J. The resistivity values below the lines are in the ranges of 0.120-200 Ωm. At a depth about 13.5 m to 26.9 m, it may identify as a presence of seawater intrusion because it has a small resistivity range between 0.120-0.980 Ωm [16]. Based on the literature study, the seawater intrusion saturated at clay layer obtained the resistivity values < 1 Ωm [19]. For other resistivity values are thought to be a layer of clay and sand that has a range of 1-100 Ωm resistivity to clay and sand 1-1000 Ωm. This is supported by geological maps as well, where the Tanah Mas area is included in the coastal plain which generally consists of clay and sand.

2D Resistivity images from six perpendicular lines then collected to 3D data sets then processed by Rockwork software. 3D resistivity images (Fig.3) which allows resistivity variation in all possible directions (vertical and horizontal) successfully show the inverse models of the subsurface resistivity accurately and reliably [8]. Distribution pattern of seawater intrusion in the 3D resistivity images are shown in reddish pattern (Figure 3). Based on the distribution pattern shown in the fig.3 (a) and (b), it turns out that the river located to the west of the area has also been contaminated with saltwater and intrudes around the river area. Distribution of seawater intrusion has reached northern, eastern and southern part of Tanah Mas area. Seawater intrusion in the study area is predicted as a result of the sea-level fluctuations of the Java Sea and by continuous change in coastal groundwater levels due to pumping or over exploitation.

Based on rainfall data 2013, 2014, and 2015, the research location located in the northern part of Semarang city has relatively less rainfall compared to other parts. This condition became one of the causes of research sites located in the northern region experienced intrusion of seawater. Map of rainfall counter for three years in the area as in Fig.4.



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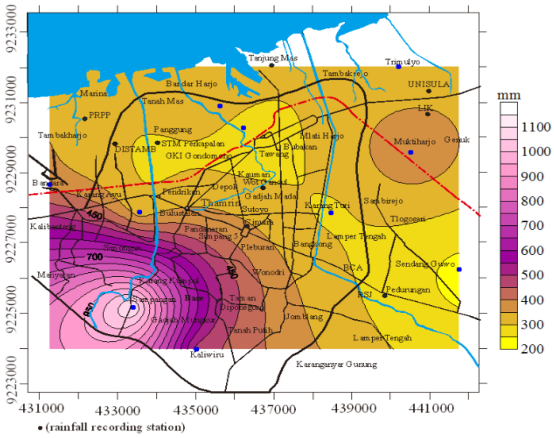

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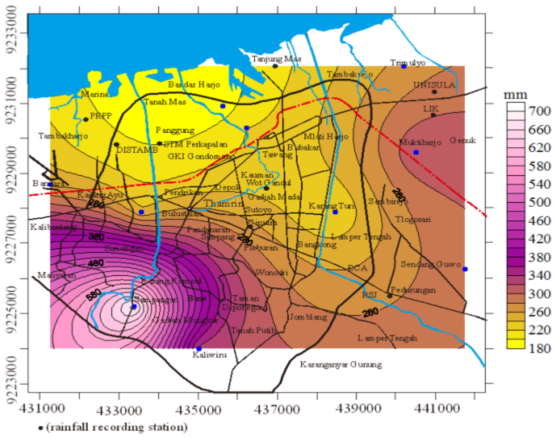

(2015)

Fig.4 Map of rainfall contour for 2013 to 2015 in area

The results of measurements made continuously since 2010, 2011, and 2013 by Sudaryanto *et al* [23] show the condition of several damaged monitoring wells in Semarang. These broken criteria are:

1. Changes in depth reported to be shallower. This is caused by the process of sedimentation in a wellbore or a broken well.
2. Changing groundwater flow patterns to a linear pattern characterized by homogeneous groundwater temperatures with depth. This characterizes the absence of groundwater flow in the well which can be caused by blockage of the well filter (screen).

5. CONCLUSION

The seawater intrusion has occurred in Tanah Mas area, Semarang, Indonesia which has been tested using precipitation data and resistivity methods. In October, the coastal aquifer will be so pressed by salt water that sea water intrusion penetrates into freshwater areas. In November, the coastal aquifers are recharged by precipitation, and replenished water flowing to the sea will prevent saltwater from encroaching into the area of freshwater.

The presence of seawater intrusion indicated by small resistivity range between 0.120-0.980 Ωm. The other resistivity value is thought to be presence of clay and sand that have a range of 1 Ωm to 100 Ωm resistivity and 1 Ωm to 1000 Ωm sequentially.

The 3D resistivity images show the distribution pattern of seawater intrusion that has reached northern, eastern and southern parts of Tanah Mas area. Seawater intrusion in the study area is predicted as a result of the sea-level fluctuations of the Java Sea and by continuous change in coastal groundwater levels due to pumping or over exploitation.

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