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GEOPHYSICAL AND HYDROCHEMICAL APPROACH FOR SEAWATER INTRUSION IN NORTH SEMARANG, CENTRAL JAVA, INDONESIA

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ABSTRACT: Groundwater over exploitation leads to seawater intrusion in coastal area and influence the quality of the groundwater aquifers. Geophysical and Hydrochemical investigations were carried out to determine subsurface geologic formation and assessing seawater intrusion in Tanah Mas Residential area of North Semarang, Indonesia. The seawater intrusion was investigated by 2D geoelectrical resistivity imaging and generated using multi-electrode system with Wenner array configuration. Chemical analyses of groundwater samples of indicated the range of salt concentrations meanwhile correlation of geophysical data in the study area allows for the predictions of seawater-contaminated zones and their influence on in situ salinity in the study area. The 12 geo-electrical sections were obtain up to penetration depth of about 27 m for a total length of 150 m. The results of groundwater chemical testing indicated that there are three groundwater samples with high levels of chloride ions. The three groundwater samples with high levels of chloride ions are from wells F (434455, 9231239), J (434610, 9230204) and M (434117, 9231156). Seawater intrusion in the study area were also detected and confirmed by the resistivity measurement. It can be concluded that the seawater intrusion has reached the north, east and southern parts of the Tanah Mas Residential area.

Keywords: Seawater intrusion, Tanah Mas, Geophysical, Hydrochemical

1. INTRODUCTION

Groundwater is a renewable natural resource that has important role towards living [1]. The increase of human population, the extensive withdrawal of groundwater, and the climate change effect have and will impact the groundwater level [2][3]. It has been showed that groundwater over exploitation leads to seawater intrusion in coastal area and influence the quality of the groundwater aquifers [4]. Seawater intrusion constitutes the main environmental problem facing coastal aquifers worldwide [5][6][7]. Seawater intrusion is a global issue, exacerbated by increasing demands for freshwater in coastal zones and predisposed to the influences of rising sea levels and changing climates [8]. The case of sea water intrusion is a problem that often occurs in the coastal areas, the problem is always related to the needed of clean water. Applying a management plan to coastal aquifers prerequisites understanding of the origin and distribution of saline waters [9]. Salinity measurements in wells and hydrological modeling are efficient methods for the study of seawater intrusion [10].

Semarang is a big city in Indonesia located on one of small deltas in the world and experiences an important urban growth. This developing city has experienced groundwater overexploitation, salt intrusion, land subsidence, and coastal inundation due to urban growth. Today population density in Semarang City reached 764,487 [11]. As population growth and urban development in Semarang City increase, the water stress rises significantly on groundwater. Moreover, the city experiences long-term salt water intrusion [12][13]. Tanah Mas residential 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 and could lead to the phenomenon of seawater intrusion.

In studying the thickness and geometry of depositional systems in subsurface, a common procedure is to make use of information from geological research, drilling, and exploitation boreholes. However, these methods are expensive and time consuming, preventing their use on a large scale. Using geophysical measurements can provide a less expensive way to improve the knowledge of a set of boreholes [14]. For this reason, in many cases, geophysical prospecting techniques can provide complementary data that enable geological correlation, even in sectors where there are no data from boreholes. Indirect geophysical methods (like electrical resistivity and VES surveys) generate continuous data throughout a given profile. It helps in understanding spatial relations between fresh, brackish, and saline water, which commonly coexist in coastal aquifers.

Geoelectrical resistivity imaging has been used to address a wide variety of hydrological, environmental and engineering problems [15][16][17]. The geoelectrical resistivity technique is one of the geophysical methods, which enables the determination of sub-surface resistivity by introducing artificially produced electric current into the ground through a set of two electrodes, and measuring the potential field generated by the current by the aid of another set of two electrodes [18].

Based on previous research geoelectric methods were applied to monitor seawater intrusion in different parts of the world, see for examples: Cimino et al. [19] carried out vertical electrical sounding in the coastal plain of Acquedolci (Northern Sicily-Italy) to assess seawater intrusion, Khalil [20] studied the salt water intrusion from the Gulf of Suez by applying a direct current resistivity geoelectric method, Mogren [21] Saltwater Intrusion in Jizan Coastal Zone, Southwest Saudi Arabia, Inferred from Geoelectric Resistivity Survey, Rao et al. [22] Geophysical and Geochemical Approach for Seawater Intrusion Assessment in the Godavari Delta Basin, A.P., India, while De franco et al. [23] Monitoring the saltwater intrusion by time lapse electrical resistivity tomography: The Chioggia test site (Venice Lagoon, Italy).

Groundwater chemistry has been successfully employed to evaluate seawater intrusion in coastal aquifers by different authors [24][25][26][27]. The parameters observed in this research were the level of sodium and chlorides ion level. High total chloride, and sodium concentrations in the study area has prompted us to take up geophysical investigation to delineate high salinity zones through use of resistivity method by looking at the nature of subsurface geological formations. The present study was conceived to help reveal the extent and assess the seawater intrusion, if any into the coastal aquifer based on a combined analysis of geophysical and hydro-chemical data.

2. METHOD

2.1 Chemical Analysis of Groundwater Samples

Chemical analysis of groundwater samples from production wells were performed to examine the characteristics of seawater intrusion in the study area. Groundwater samples were tested in laboratory using the AAS and Argentometry analysis method INS 6989.19: 2009 to determine the sodium and chlorides ions level. The parameters observed were the levels of Cl^- and Na^+ ions contained in the sample water wells. The parameters observed for Cl^- concentration in sea water is the most dominant ion among other ions [8][28]. References [28] states that Cl^- ions can bind with other ions in sea water including Na^+ ion, SO_4^{2-}, and HCO_3^-, but the most common is the Cl^- ion binds to Na^+ ions.

2.2 Geoelectrical resistivity imaging survey

The principle of the resistivity method is to inject electrical current into the earth through the current electrodes (a pair of electrodes) and a response is received in the form of a potential difference is measured via two electrodes potential. From the measurement results of current and electric potential difference, can be obtained by variation of electrical resistivity in the layer below the measuring point [29][30].

Geoelectrical resistivity imaging lines were measured using resistivity meter multichannel S-Field at Wenner array configuration. The survey was conducted during the December 2015. The geoelectrical lines were traverses 150 m in length. The electrode spacing was 10 m with a total of 16 electrode positions for each traverse line. The data were processed using two softwares, RES2DINV for 2D profiling. The geoelectrical profiles shown resistivity values that varied laterally with depth, in the vertical aspect, two levels could be distinguished in accordance with the resistivity values obtained.

3. RESULT AND DISCUSSION

3.1 Result of Hydrochemical Testing

Chemical testing of groundwater samples were carried out as an early indication of the intrusion of sea water in the research area. The parameters measured were the levels of chloride ions contained in the groundwater samples. Groundwater samples were taken from 13 points wells that used by the people in the area. The water samples were then tested using the argentometry analysis method INS 6989.19: 2009 to determine of chloride ions level. The test results of chloride ions level in groundwater samples are presented in Table 1.

From the results shown in table 1, there are three groundwater samples that has high levels of chloride ions. three groundwater samples had high levels of chloride ions that are in s F, J and M. High levels of chlorides ion means the samples have chlorides ion levels more than 250 mg/l in groundwater. The high levels of chloride can be used as an indication that there has been a seawater intrusion in the area. Referring to the research that conducted by Werner *et al.* (2013) that the primary

Figure 1 Location map of the investigated area showing the resistivity measurements and well location

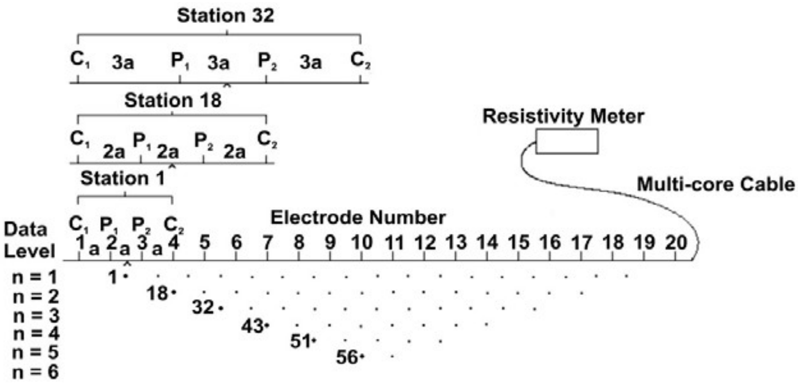


Figure 2. Sketch of the electrodes for the 2D electrical resistivity survey and the sequence of measurements for building the pseudo-section [31]

Table 1 Testing results of chloride and sodium ion levels from groundwater samples

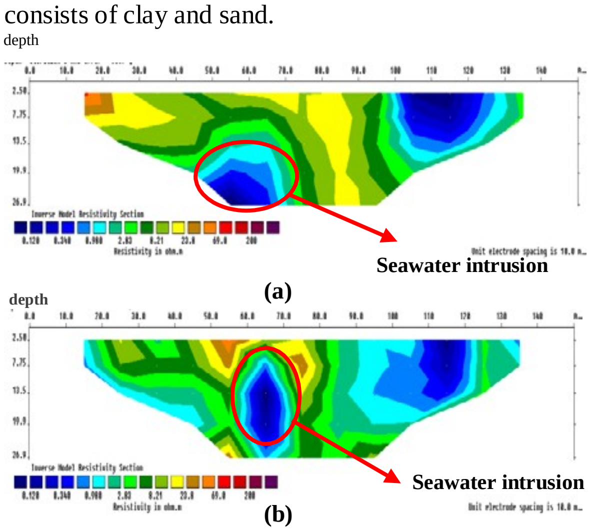
Sample	Coordinate (UTM)	Chlorides concentration (mg/l)	Sodium concentration (mg/l)
A	434696, 9230800	123	46.7
B	434755, 9231133	191	43.5
C	434582, 9231258	92	49.5
D	434503, 9230761	216	43.4
E	434358, 9231053	245	45.2
F	434455, 9231239	2489	49.5
G	434554, 9230518	118	40.3
H	434894, 9230518	130	40.2
I	434815, 9230580	76	45.4
J	434610, 9230204	869	49
K	434124, 9230093	68	49.6
L	434062, 9230541	121	49.1
M	434117, 9231156	588	51.9

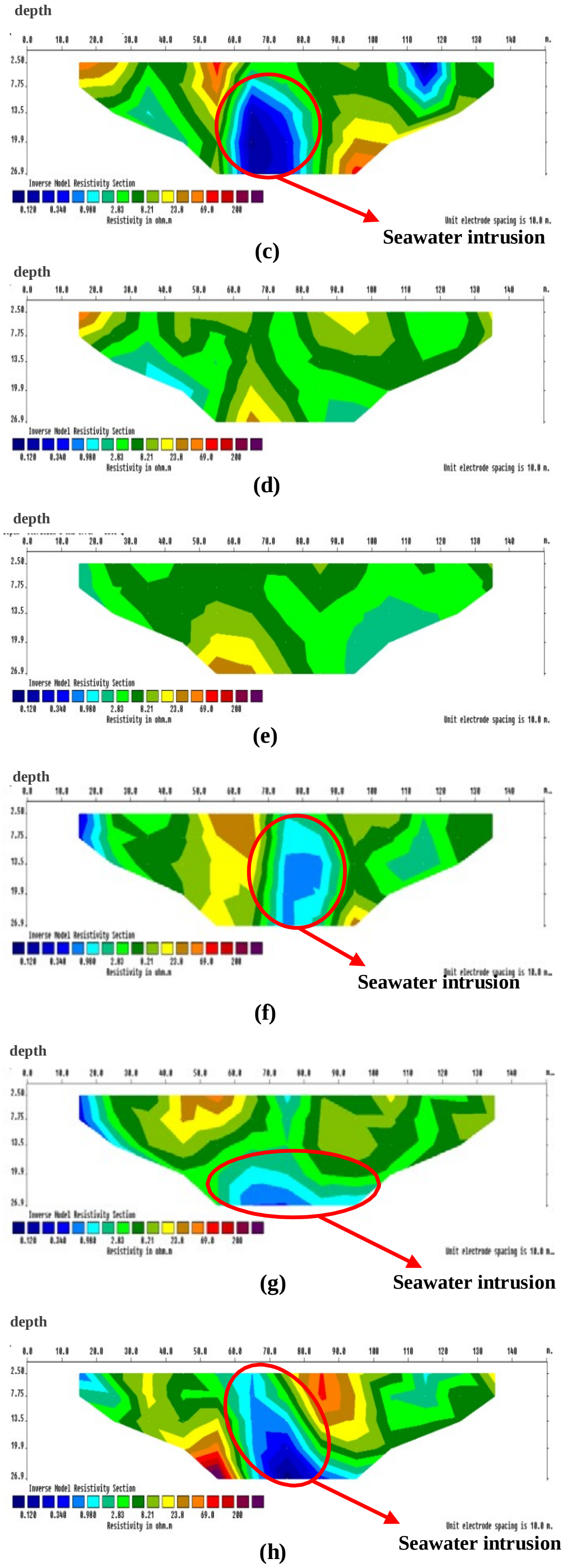
detrimental effects of seawater intrusion are reduction in the available freshwater storage volume and contamination of production wells, whereby less than 1% of seawater (~250 mg/l chloride) renders freshwater unfit for drinking [8].

3.2 Result of Geoelectrical Survey

Resistivity measurement has been conducted to determine the distribution of seawater intrusion in Tanah Mas residential. The profiles acquired across the study area using a multi-electrodes acquisition system in a wenner array configuration with electrode spacing of 10 m were used for the profiling. The twelve geoelectrical line were obtain up to penetration depth of about 27 m for a total length of 150 m. 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 [13].

Sea water intrusion in the Tanah Mas Residential North Semarang was detected by measuring the resistivity of the line 1 and 2 are located at Telaga Mas Raya street, line 3 which is located at Muara Mas Raya street, line 6 and 11 are located at Tanjung Mas Raya street, line 7 and 8 are located at Tanjung Mas Raya street, line 9 at Tanggul Mas raya street, as well as lines 10 and 12 are located at Sumber Mas Raya street. Seawater intrusion saturated at clay layer that obtained the resistivity values < 1 Ωm [22]. For other resistivity values are thought to be a layer of clay and sand that has a range of 1 Ωm to 100 Ωm resistivity to clay and sand 1 Ωm to 1000 Ωm. Based on the geological map, Tanah Mas Residential areas that including the coastal plain which generally consists of clay and sand.





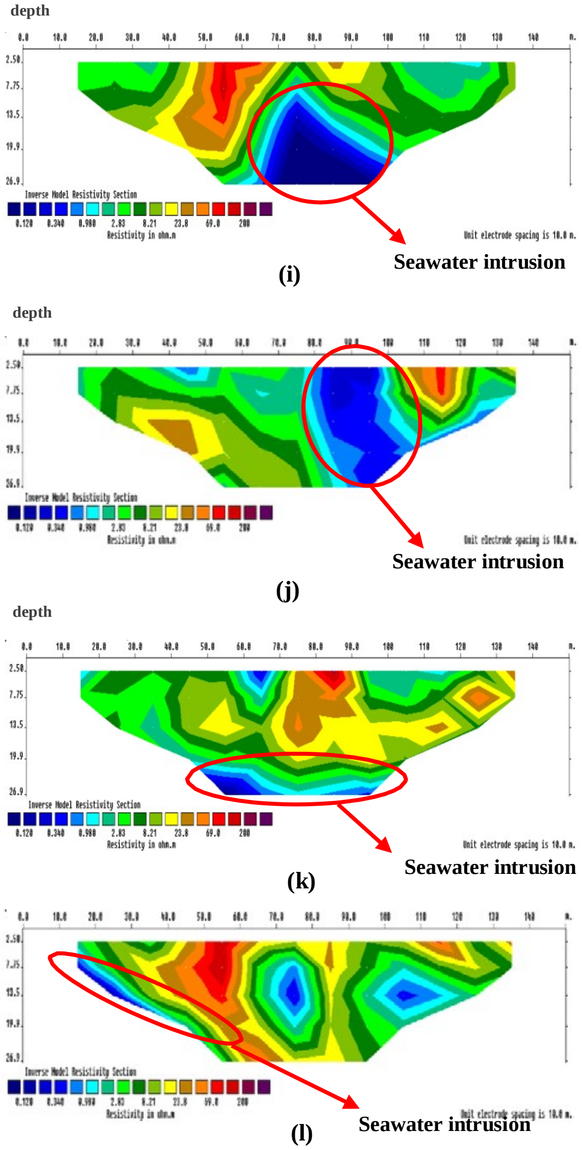


Figure 3 The 2D subsurface resistivity profiling of (a) line 1, (b) line 2,(c) line 3, (d) line 4, (e) line 5, (f) line 6, (g) line 7, (h) line 8,(i) line 9,(j) line 10, (k) line 11, (l) line 12

At the resistivity profiles line 8 and line 10 obtained resistivity patterns are discontinuous, it is thought to be a weak zone caused land subsidence is the effect of groundwater pumping is continuous. Based on previous research, that the extraction of ground that continuously can cause land subsidence in the area [32][33]. So small resistivity reaches the surface of the seawater seeping allegedly at the weak zone.

4. CONCLUSION

Phenomenon of seawater intrusion has taken place in Tanah Mas residential north of Semarang. This is confirmed by the present studies using chemical testing and resistivity method. From the results of chemical testing, there are three groundwater samples that has high levels of chloride ions. Three groundwater samples had high levels of chloride ions that are in wells F, J and M. Seawater intrusion in the study area were also detected and confirmed by the resistivity measurement. The seawater intrusion was detected by measuring the resistivity of the line 1 and 2 are located at Telaga Mas Raya street, line 3 which is located at Muara Mas Raya street, line 6 and 11 are located at Tanjung Mas Raya street, line 7 and 8 are located at Tanjung Mas Raya street, line 9 at Tanggul Mas raya street, as well as lines 10 and 12 are located at Sumber Mas Raya street. It can be concluded that the seawater intrusion has reached the north, east and southern parts of the Tanah Mas Residential area.

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