Modeling of Seawater Intrusion in Karst Area of Tuban Region, East Java Province, Indonesia

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Abstract

Carbonate aquifer in coastal areas is very susceptible to seawater intrusion, especially if groundwater exploitation is high. To identify the distribution of seawater intrusion both horizontally and vertically, hydrophysics and geophysical-resistivity surveys have been carried out. Investigations were carried out at 143 observation points in the form of dug wells, boreholes, and springs to obtain seawater intrusion's horizontal and vertical distribution. In situ measurement of groundwater's electric conductivity and pH is carried out using portable instruments. The geoelectric resistivity investigation using the vertical electrical sounding with Schlumberger array was carried out at 25 points. The results of the hydrophysics survey are presented in the maps of groundwater flow direction, the distribution of electrical conductivity, and pH. These three maps show that the horizontal distribution of seawater intrusion occurs along the tributary pattern. Based on the geoelectric profile, the groundwater conditions in the study area can be classified into three zones; freshwater, saline water in the karst plane, and saline water in the hilly area. The saline water in the hilly region is interpreted as connate water. After this study, it can be concluded that seawater intrusion in the karst plain topography is classified as a natural process, and developing mangrove forests along tidal rivers may be the best option to prevent widespread seawater intrusion.

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1 Introduction

Tuban District, East Java Province, Indonesia, has coastal areas approximately 150 km long. Almost all the coastal areas are directly adjacent to the karst area. The freshwater for domestic, agriculture, and fisheries along the coast is taken from a limestone aquifer. The increasing exploitation rate in the last two decades has the anxiety for the widespread seawater intrusion. The degradation of freshwater quality due to seawater intrusion is a severe societal issue in most coastal areas (Zghibi et al., 2019). Hydro-physics and geophysical-resistivity methods have been investigated to acknowledge this condition.

Seawater intrusion is a process where the seawater mass is transported into zones saturated with freshwater. The movement of the seawater often marks it into the freshwater system (Bear et al., 1999). The altering process of the freshwater into brackish water could be caused by several things, such as seawater intrusion, effects of the presence of deep brine water, The freshwater and salt-contained rocks, or the occurrence of a surface pollutant seeped through to the freshwater table (Khaska et al., 2013). Seawater intrusion is a natural process. However, it could be accelerated by human activities such as the exploitation of freshwater, which has a higher extraction rate than its recharge rate. The phenomena could also be caused by the decreasing rate of rainfall water infiltration at the coastal area and the rise of seawater levels (Kelly, 2006). The movement process of the seawater into the freshwater system could quickly occur at the limestone aquifer because of its high permeability (Linzey, 2011).

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2 Research Area and Method

The investigation site is located within 112° 4′ 42,159″–112° 12′ 21,248″ eastern longitude, 6° 53′ 47,904″–6° 58′ 59,832″ southern latitude. Administratively, it is situated in Tuban District, East Java, Indonesia. Hydrophysics studies are done with 143 observation wells, including 114 dug wells, 25 drilled wells, and four water springs. Both dug and drilled wells can be found almost all over the investigation site except in the southeastern area. The measurement of water table depth, water temperature, pH, and electrical conductivity are taken at each dug well during the hydrophyisics studies. Those measurements are using a hand-held instrument.

The geophysical-resistivity measurements have been done on 25 points with Schlumberger configuration. This is to collect the material's resistivity value vertically at each measurement point. The electro-stratigraphy profiles of the investigation site are obtained by correlating the measurement results from each point. The correlation uses a north–south orientation after the subsurface layer's inclination model. The profile slicing uses a west–east direction to visualize the seawater intrusion's horizontal spread.

3 Results

3.1 Physiography and Geology

Based on the physiography of Eastern Java Island, the study area is located on the Rembang-Madura Zone, formed by the anticlinorium structure with the axis orientation from west to east. The fault structures in this area have a northwest-to-southeast direction. The shallow marine sedimentary rock, carbonate rocks, and land sediment construct this zone.

The southern part of the research area is low-sloping hills composed of fine sedimentary rocks with some lenses of carbonate sandstone. The carbonate rock is widely spread in the northern region, forming the karst topographic, marked with mesa and butte, water springs, and karst cave at the western part of the research area. The carbonates material in the northeastern region is advance eroded, thus building an alluvial plain. However, there are several isolated hills composed of reef limestones. Semi-meander rivers affected by the sea's tides flow through the karst plain.

3.2 Hydrogeology and Hydrophysics

The depth of the groundwater table in the study area ranges between 0.34 and 92 m from sea level, and groundwater flow generally from the south to the north and northeast. The shallowest point is the springs in the western part of the study area. However, the deepest point is a natural well in the center part that is interpreted as a doline. The groundwater level ranges from the highest point in the middle spring to the lowest point in the dug well in the northeast.

The electric conductivity of groundwater lies between 580 μS/cm and 7410 μS/cm. The highest EC value was found on water samples from north and northeastern parts, while the lowest was in the middle. Some high values of EC can be located in the southwest of the study area (Fig. 1). A

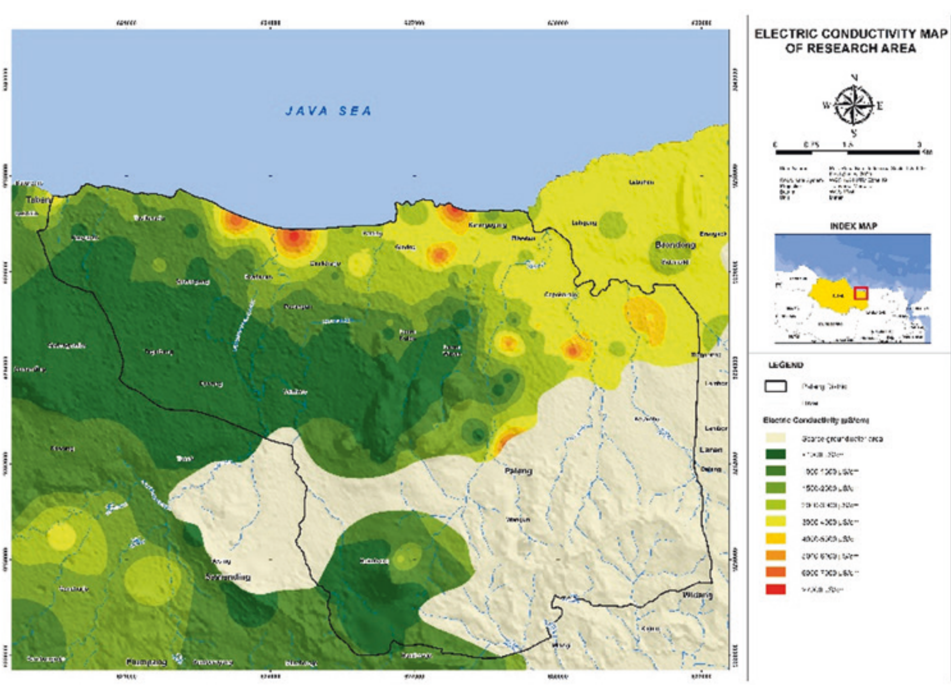

Fig. 1 Distribution of electric conductivity values of groundwater

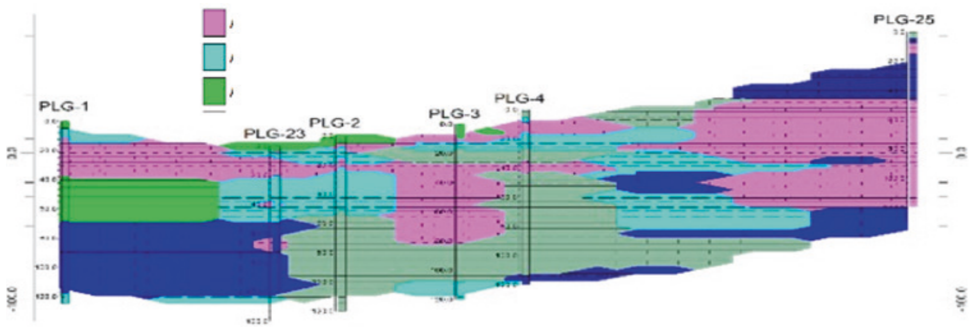

Fig. 2 Vertical distribution of resistivity in the northeast part of the study area

very high EC value (> 7000 μS/cm) was found at the dug wells in the middle part. The high-value EC values in the north and northeast part illustrate a process of mixing seawater with freshwater.

3.3 Resistivity Geoelectric

Geoelectrical resistivity has been a favorite geophysical method than other because of the wide range of resistivity values (Barker, 1980). The results of geophysical investigations are described on a profile of groundwater resistivity in two-dimensional modeling of the north–south line (Fig. 2). After this figure, the saline water can be found in the north (coastline) and south (hilly area), also in the middle (karst plane). Saline water is also found in shallow groundwater in the karst plains.

4 Discussion

The EC map shows that the horizontal distribution of brackish and brine water takes place along the tributaries' pattern. Even though in the northeast part, the brine water has been founded in a dug well 4 km from the coastline. The high EC value is probably due to the intrusion of seawater into the groundwater system via rivers during high tide.

The geoelectric profile of groundwater conditions can be classified into three zones; fresh water, saline water in the karst plane, and saline water in the hilly area. The saline water in the hilly region is interpreted as trapped seawater while forming fine-grain sedimentary rocks. The saline water in the karst plain topography is a product of seawater intrusion. Developing mangrove forests along tidal rivers may be the best option to prevent widespread seawater intrusion.

5 Conclusion

In light of the findings, it is imperative to recognize the dynamic interplay of natural geological processes shaping the hydrogeological landscape. Seawater intrusion in the karst plains, elucidated as a natural phenomenon, emphasizes the intricate balance between saltwater and freshwater systems in coastal regions. The identification of saline water in the hilly area as connate water signifies its ancient origin, deeply embedded within the geological formations. This insight into the origin and nature of saline water sources not only enriches our understanding of the region's hydrology but also lays the foundation for informed decision-making in water resource management. These conclusions underscore the necessity for adaptive, nature-based solutions and robust policies to safeguard groundwater quality, ensuring the sustainability of vital water supplies for both current and future generations.

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