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Connate Water Distribution Zone Affecting Groundwater Quality of Semarang City Coastal Plain

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ABSTRACT

Semarang City Coastal Plain is an alluvial plain with groundwater conditions that have a salty, slightly brackish, or brackish taste, and some are fresh. The limited availability of fresh water on alluvial plains is caused by several factors, including the influence of seawater on coastal aquifers. There is connate water or water trapped in the clay layer will affect the quality of groundwater to be brackish or salty. Connate water is water trapped in the cavities of sedimentary rocks, since the deposition occurred. The process is caused by seawater entering the land, or seawater that is trapped during the sedimentation process. The results of the study using the hydro stratigraphic estimation method showed that there were several distributions of salt water that were trapped or trapped in the cavities of sedimentary rocks along the coastal plain of Semarang city. The trapped salt water can be predicted to be caused by the phenomenon of connate water. Based on map data, it is shown that the coastline of the city of Semarang around the 900s, is in the Simongan area with a line extending eastwards along the Brintik or Bergota mountain area. Geological and sedimentation factors cause changes in the coastline towards the north, and can result in salt water being confined or trapped in rock cavities.

1. Introduction

Groundwater is one of the good raw water resources to meet primary needs compared to other clean water sources. The need for clean water always increases according to the increase in population which always increases from year to year [1]. On the coastal area, there are areas or zones that are in direct contact between fresh water coming from land and salt water from the sea, this zone is known as the contact plane or interface [2]. The greater the groundwater discharge, the more upright and closer to the coastline, on the contrary, the smaller the groundwater discharge, the seawater will press and protrude into the land [3]. The water balance study between groundwater availability and seawater intrusion provides an overview of the condition of the aquifer, the dynamics

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of groundwater potential and the spread of seawater intrusion [4]. Groundwater from the land flows into the sea through the medium aquifer, while seawater seeps into land due to hydrostatic pressure. Thus, the urgency in the plane of interface between seawater and fresh water can shift, if strong seawater urges fresh water, there is an infiltration of seawater into fresh water so that the water tastes salty [5].

Semarang City Coastal Plain is an alluvial plain with groundwater conditions that have a salty, slightly brackish, or brackish taste, and some are fresh. The existence of connate water will affect the quality of groundwater to be brackish or salty. Connate water is groundwater trapped in the cavities of sedimentary rocks, since the deposition occurred, including in this condition is water trapped in the cavities of melted igneous rocks as magma is sprayed out to the surface [6,7]. Its origin can be due to seawater entering the land, or seawater trapped during the sedimentation process.

This current research fills in the gap in the groundwater research in the coastal area, since most of the research identified the factor influencing the groundwater quality in coastal area is saltwater intrusion. This current research investigated another factor influencing the groundwater quality in coastal areas which is connate water. The connate water or the salt water trapped within sedimentary rocks at the time of their deposition at the coastal area of Semarang is identified using geoelectric method. The author believed that identification of connate water in Semarang coastal area is important since connate water can play an important role in the distribution and quality of groundwater resources.

2. Groundwater Movement Pattern

Rocks that can store and drain groundwater are called aquifers. The natural use of groundwater is to take groundwater that appears on the surface as spring water or artificially. The groundwater flow model begins in the recharge zone. This area is an area where water that is on the ground surface, both rainwater and surface water, undergoes a process of gravitational infiltration (infiltration) through pore holes soil/rocks or gaps/fracturing in soil/rocks. This infiltration process will accumulate at one point where the water encounters a layer or rock structure that is impermeable. This accumulation point will form a saturated zone which is often referred to as a discharge zone. The natural condition of Indonesia has amount of water availability [8]. Differences in physical condition will naturally result in water in this zoning will move/flow both by gravity, pressure difference, control of rock structure and other parameters. This condition is referred to as groundwater flow. This groundwater basin is hereinafter referred to as the flow zone.

Along the way, this groundwater flow often passes through an aquifer layer on which has a watertight (impermeable) overburden, this results in a change in pressure between groundwater that is under the overburden and groundwater that is above it. This change in pressure is defined as confined aquifer and unconfined aquifer.

3. Groundwater Flow Model

Under natural circumstances fresh groundwater flows into the ocean through aquifers in coastal areas related to the ocean on beaches jutting into the sea. But due to the increasing need for fresh water, the flow of fresh groundwater towards the sea decreases, or even vice versa, seawater flows into the aquifer mainland. This incident is called seawater intrusion. The cause of occurrence is because the Aquifer is related to seawater and the decrease in water level is quite large. The interface between fresh groundwater and saltwater can be seen in Figure 1.

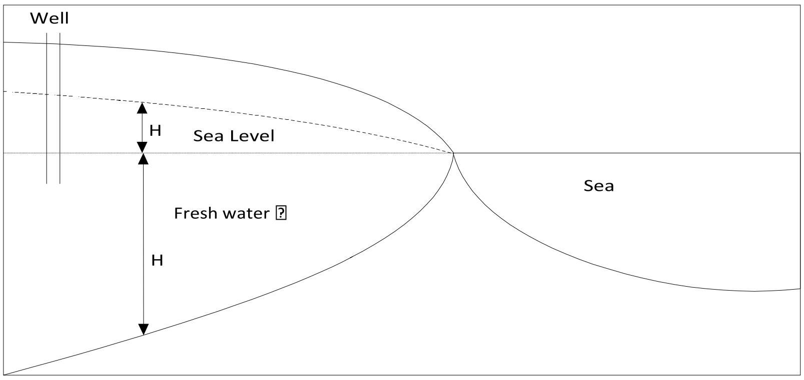

Fig. 1. Interface between fresh groundwater and salt water [4]

Apart from the possibility of seawater intrusion, coastal plains can generally occur high tide floods or known as tidal water. This event occurs in coastal plain areas whose elevation or ground level is lower than the tide sea level.

The groundwater on the coastal alluvial plains is usually salty. This is due to the influence of the sea. According to Fetter [10], coastal aquifers have salty groundwater. The saltiness of groundwater is caused by two things, namely: the first is due to connate water trapped in the aquifer, the second is due to the intrusion of salt water into groundwater. Connate water is water that is trapped in a rock formation at the time the formation is formed. According to Seyhan [11], connate water is water that is trapped in some sedimentary or mountain rocks at the time of its origin. Such water is usually highly mineralized.

4. Method

4.1 Research Location

The spatial approach was employed as in analysing data, it aimed to identify land use patterns, and soil layer structure.

The research location in Semarang City, geographically located between 6^o 50'–7^{o}10' LS and between 109^{o}50'-110^{o}35' BT. According to its administrative boundaries, Semarang City in the north is bounded by the Java Sea, in the south it borders Semarang Regency, in the west it borders Kendal Regency and next to the east borders Demak Regency. Based on the topographical state, the northern part to the coastal area is lowland, while the southern area consists of hilly areas. The study area covers a lowland area with an area of 117.1 km^2. The map of Semarang city can be seen on the Figure 2. The subsurface lithological conditions of the coastal area of Semarang City consist of fine fractional sediments that are soft and relatively dense sands based on volcanic rocks below depth 20 – 25 meters.

Determination of physical object data was conducted by field observations and measurements using geoelectric estimation methods. Geoelectric method as one of the geophysical methods is based on the application of the concept of electricity to earth problems. The goal is to estimate the electrical properties of a medium or sub-surface rock formation, particularly its ability to conduct or inhibit electricity (conductivity or resistivity). Selection and measurement of samples for geoelectric estimation using the area sample method or sampling area, namely by dividing the research area into groups of sample areas, based on the geological conditions of the region.

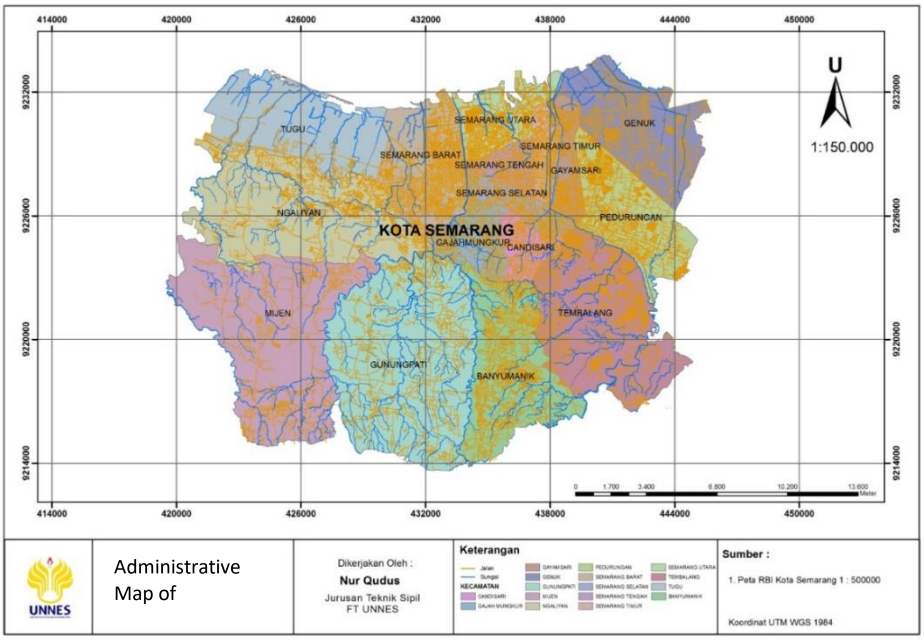

Fig. 2. Administrative map of Semarang city

4.2 Research Tools

The tools used to obtain physical object data in this study, as shown in Figure 3, consisted of

(a) Geoelectric estimation measurement using resistivity meter, which consists of current electrode made of stainless steel, potential electrode made of copper, 2 (two) cable winds for current electrodes along 400 meters, 2 (two) winds of wires for potential electrodes along 60 meters.

The measurement method uses the Schlumberger circuit geoelectric method, which is a circuit used to determine the depth and thickness of the layer in an inward or vertical direction. The working principle is that direct electric current is flowed into the ground through 2 (two) electrodes of current plugged into the soil. The magnitude of the strong current flowing into the ground is measured with an ammeter. The change in ground potential due to electric current is measured through 2 (two) potential electrodes plugged in between the two current electrodes.

The research implementation uses a set of Resistivity meter type G-Sound (GL-4100), GPS (Global Positioning Systems), place height gauge and slope gauge. Tool Specifications

(i) Controlled AB voltage: 0 - 400 V
(ii) AB current max: 100 mA
(iii) Injection time: 4 - 5 s
(iv) Volt meter range: 0 - 1000 V
(v) Ampere meter range: 0 - 400 mA.

(b) Global Positioning Systems (GPS) are used to determine the coordinates of the location of measurement points in the field. Using this tool can be determined the coordinates of each measurement sample point. GPS used brand Garmin GPS Map type 76CSx.

(c) Measurement of the permeability coefficient is carried out using the Guelph permeameter type 2800. The equipment consists of a permeameter, field tripod, and hand drill.

Fig. 3. Research tools

5. Results and Discussion

The research area is located on the coast of Semarang City from east to west. In general, the height of the land in the coastal area of Semarang City varies quite a bit from 0 m to 60 m. The north close to the coast has a flat topography with a height of zero meters, the topography towards the south is getting higher because it approaches the hills. The West Semarang region has a topography between 0-15 meters above sea level, with a small hilly area in the south of West Semarang District, while in North Semarang District at an altitude of 0-4 meters from sea level it has no hills. Similarly, the rest of the district is higher than the hills. The Figure 4 shows the map of all districts of Semarang city.

The research was carried out on the coastal plain of Semarang city which stretches from the east and west of Semarang City. The research administration area includes the following sub-districts: Tugu, West Semarang, Central Semarang, East Semarang, North Semarang, South Semarang, Gayamsari, Genuk and Pedurungan. Each region is tested for data collection as a representative of the measurement point. The following map image on Figure 5 shows the points of measurement taken.

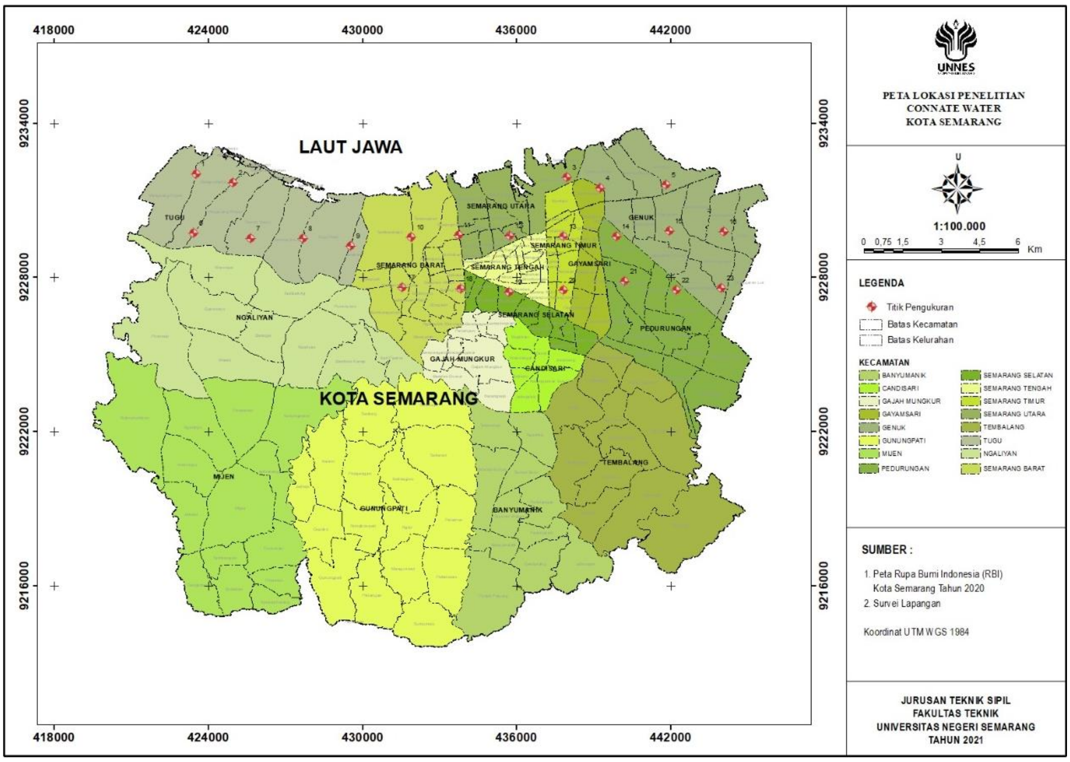

Fig. 4. Research administration area map

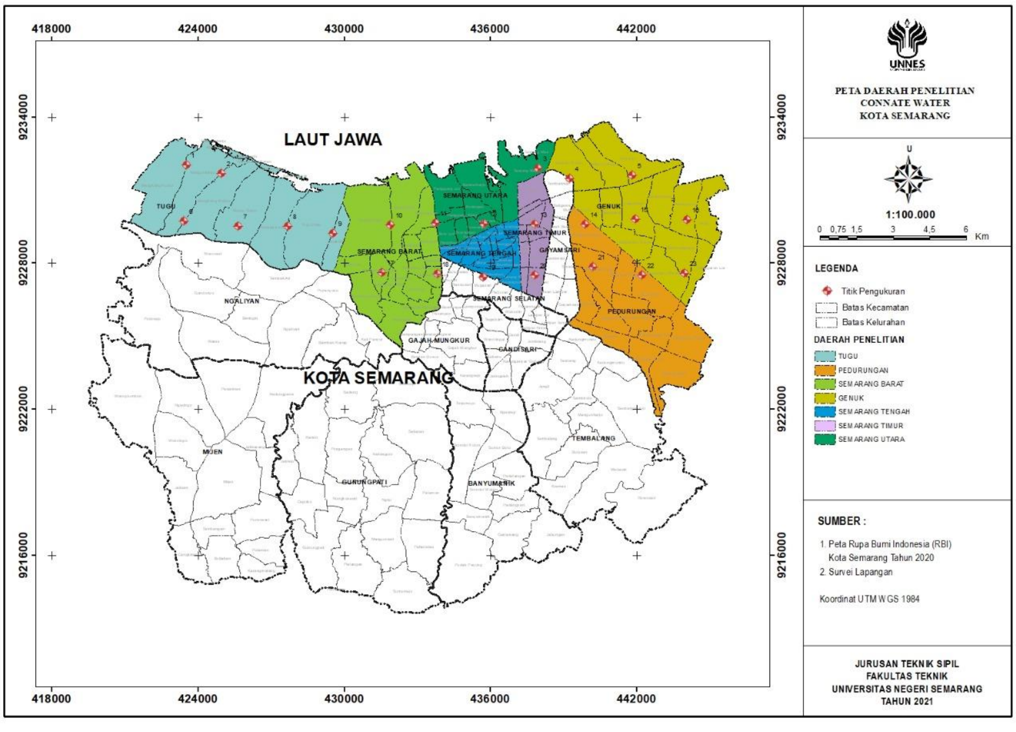

Fig. 5. Research location map

The interplay of the measurement results is carried out assuming that each rock has electrical conductivity with the price of its respective type of resistance. The same material does not necessarily have the same type of prisoner value. Conversely the price of the same type of resistance can be possessed by different rocks. Influencing factors include; lithological composition, condition of rocks, the composition of minerals contained, the content of liquid bodies and other external factors. The metal content around the estimation site greatly affects the resistance value of the rock type.

5.1 Aquifer Hydrostratigraphic Model Preparation

Geoelectric estimation is one of the research methods to determine the arrangement of layers of rocks or material constituting the aquifer vertically from the soil surface. This estimation uses the principle that rock layers or materials have different resistivity values. Factor factors influencing the large small value of the type of resistance are (a) the type of material; (b) water content in rocks; (c) the porosity of the rock; and (d) the chemical properties of water. Besamya resistance type is measured by conducting electric current into the earth and treating the rock layer as a current-conducting medium. Analysis of the results of processing geoelectric estimation data, then the cross section hydrostratigraphic model between geoelectric measurement points is made with the aim of determining the distribution of type resistance values vertically and spatially. The results of hydrostratigraphic analysis are described in the following figure. Figure 6 below shows the results of the geoelectric estimation at the Tugu District. The dark blue coloured section with dotted line indicates the salt water trapped in the cavities of sedimentary rocks.

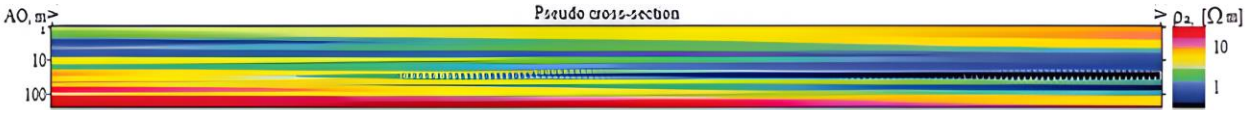

Fig. 6. Measurement Points 1 and 2, Location of Tugu District

Figure 7 below shows the results of the geoelectric estimation on measurement points 3, 4, and 5 at the North Semarang and Genuk District. The dark blue coloured section with dotted line indicates the salt water trapped in the cavities of sedimentary rocks.

Fig. 7. Measurement Points 3, 4 and 5, Location of North Semarang and Genuk Districts

Figure 8 below shows the results of the geoelectric estimation on measurement points 6, 7, 8, and 9 at the Tugu Sub-district. The dark blue coloured section with dotted line indicates the salt water trapped in the cavities of sedimentary rocks.

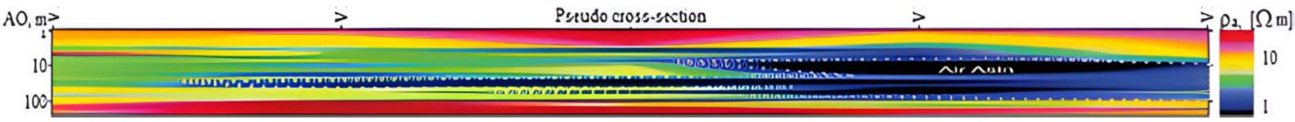

Fig. 8. Measurement Points 6, 7, 8 and 9, Tugu Subdistrict Location

Figure 9 below shows the results of the geoelectric estimation on measurement points 11 and 12 at the North Semarang District. The dark blue coloured section with dotted line indicates the salt water trapped in the cavities of sedimentary rocks.

Fig. 9. Measurement Points 11 and 12, Location of North Semarang District

Figure 10 below shows the results of the geoelectric estimation on measurement points 17 and 18 at the West Semarang district. The dark blue coloured section with dotted line indicates the salt water trapped in the cavities of sedimentary rocks

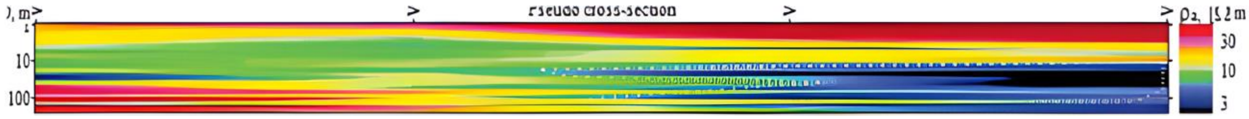

Fig. 10. Measurement Points 17 and 18, Location of West Semarang District

Figure 11 below shows the results of the geoelectric estimation on measurement points 21 and 22 at the Pedurungan district. The dark blue coloured section with dotted line indicates the salt water trapped in the cavities of sedimentary rocks.

Fig. 11. Measurement Points 21 and 22, Location of Pedurungan District

The results of the hydrostratigraphic estimation analysis above show that there is some distribution of salt water trapped or trapped in the cavities of sedimentary rocks. The trapped salt water can be predicted to be caused by the phenomenon of connate water.

Based on map data around 900-1400 on Figure 12, it shows that the lower part of Semarang City was once an ocean whose coast was located around Simongan and Mount Brintik (Bergota). However, over time and geological factors, with the magnitude of sedimentation that occurs, the land of Semarang becomes advanced or juts into the sea. In the early days of the Dutch occupation, for example, the city boundary with the sea had been located in the Old city area, and around the 1800s the water boundary was already in the current port area.

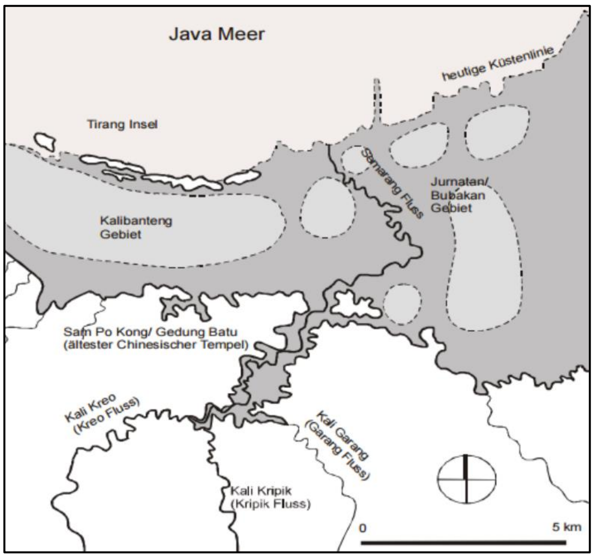

Fig. 12. Map of Semarang City in 900-1400 AD [7]

Based on the map above, the coastline of the city of Semarang is around 900, located in the Simongan area with a line extending eastwards along the Brintik (Bergota) mountain area. Then with the passage of time, there is a change in the region due to the dominant sedimentation factor, so that the shoreline juts out further north. This finding is consistent with Setyowati [13] and Yuliati *et* *al.,* [14] which states that Bergota was the port of ancient Semarang in the northern coastal area of Java. This is reinforced by regional information, that in the 1700s the old city was on the beach.

Considering the map of Semarang City on Figure 13, the coastline of the city of Semarang in the 900s is in the current urban area. It is also supported by the results of soil testing, showing that the Old City area is a type of clay supported by Wahyudi *et al.,* [15]. Considering this phenomenon, it can be concluded that the old city area starts from the Tugu area, in the eastern part, to the white land area, formerly the Sea area, so that sedimentation occurs on the coastline increasingly to the North.

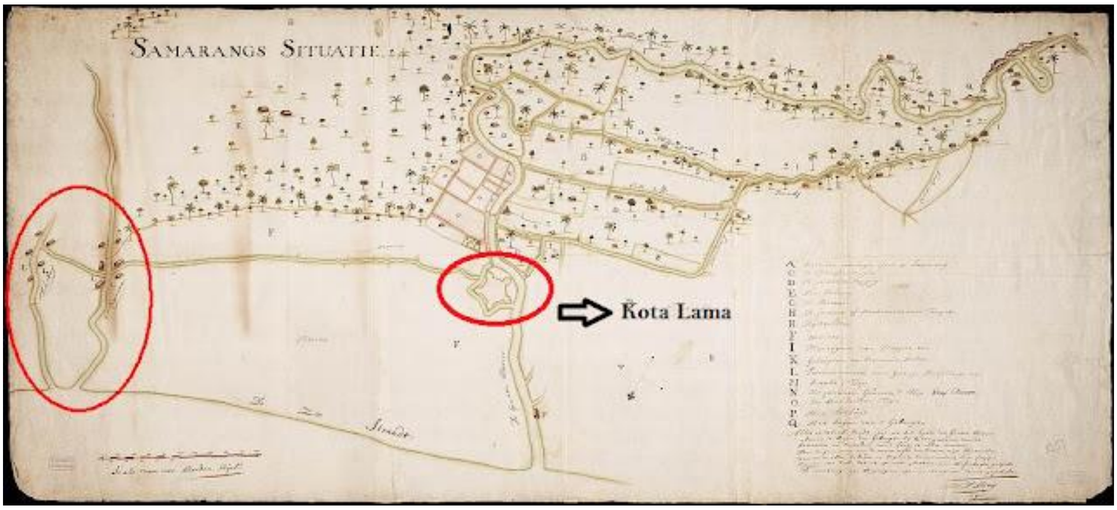

Fig. 13. Map of Semarang city in the 900s

6. Conclusion

This study uses several data analysis approaches, including the spatial approach, and the ecological approach. The spatial approach is used for the delineation and identification of land use, and the physical properties of the soil. This analysis is needed in model simulation activities, in designing the availability and needs of groundwater and the potential for connate water. The ecological approach is carried out to examine the relationship between aspects of the natural environment in the physical condition of groundwater in the Semarang coastal area.

The results of hydrostratigraphic estimation analysis show that there is some distribution of salt water trapped or trapped in the cavities of sedimentary rocks. The trapped salt water can be predicted to be caused by the phenomenon of connate water. Based on map data, it is shown that the coastline of the city of Semarang around the 900s, is in the Simongan area with a line extending eastwards along the Brintik or Bergota mountain area. Geological and sedimentation factors cause changes in the coastline towards the north and can result in salt water being confined or trapped in rock cavities.

The distribution of connate water or saltwater trapped within sedimentary rocks has been identified on several areas of Semarang Coastal Areas such as Pedurungan District, West Semarang District, North Semarang District, Tugu Subdistrict Location, North Semarang and Genuk Districts. Therefore, the connate water could influence the groundwater quality in in those areas.

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