

Mapping Model of Groundwater Catchment Area based on Geological Fault : Case Study in Semarang City

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Abstract— Groundwater is a naturally renewable resource because groundwater is an integral part of hydrological cycle. However, in reality, there are many limiting factors which influence its usage, in both quality and quantity, the provision ability of groundwater will decrease if its availability is exceeded. The problems of ground water potential in both quantity and quality are always related to its constituents' characteristics or its geological element where the groundwater resides. This present study aims at determining the groundwater catchment area based on the geological condition of an area so that groundwater recharge can be accomplished. In addition, it is necessary for groundwater catchment area to comply with the geological condition. The geologically unfit area will only result in land movement or landslide if it is used as groundwater catchment area. The results of geo-electricity analysis which was conducted in Semarang city showed that there are 3 faults; Sukorejo fault, Tinjomoyo fault and Jangli fault which will be explained in detail in the paper. Those faults intersect the underground water stream in Semarang from south to north towards the Java Sea. The majority of underground water stream in Semarang flows from south to north. In contrary, the results of the analysis showed that there are some points that become local basins such as in the south area and southwest of Semarang where flow direction is on the opposite direction. In addition, the results of the analysis showed that some coastal areas in Semarang have experienced salt water intrusion.

Keyword - groundwater catchment, geology fault, groundwater recharge, geoelectricity

I. INTRODUCTION

On the surface of the earth, water is the most basic needs for every living being including humans. Human body consists of 80% water. Water is also used for household needs, irrigation system, restaurant, hotel, and etc. If the needs for clean water are fulfilled, and then water – related problems will not occur, On the other hand, the water – related problems will occur if there is water shortage in both quality and quantity. In order to fulfill the needs of clean water, people tend to use groundwater which has relatively better quality and can be easily extracted. The groundwater extraction increases every year in order to fulfill the needs of the people, and is directly proportional to the increasing population and their needs. Barrow (2006) stated in that people in this era more numerous at many aspect than in the past and also less adaptable. It need a sustainable system which could maintain a resources such as groundwater (Dresner, 2002; Meadows, 2004)

Groundwater is one of the potential water resource and gains attentions in relation to fulfillment of clean water needs. As an effort to fulfill the needs of clean water in an area, the ground water provision is always associated with the condition of groundwater which is healthy, inexpensive, and available in quantities as needed. Groundwater is one of the better water resources for drinking water, because of the various advantages compared to other water sources. Travis (in Sudarmadji, 1988) states that the advantages of using ground water as the fulfillment of clean water among others are; it is relatively better quality than surface water and is not affected by the season, the ground water reserves are relatively larger, is easily extracted, does not need reservoir and its transmission network to distribute is cheaper.

The needs of clean water in Semarang City is increasing every year. Partial fulfillment of the needs of clean water is taken from groundwater plastering. Plastering free groundwater is conducted by extracting from wells and semi – pressurized groundwater plastering is conducted by drilling wells which is increasingly conducted in this region. If we view the current condition that the groundwater availability is relatively low and the increasing needs of various sectors, then degradation of groundwater's quantity and quality will possibly occurs. Therefore, it is necessary to study the mapping of groundwater catchment systems with due regard to the geological conditions of the fault area. After knowing the potential and the availability of the groundwater, then land – use zoning preparation and groundwater conservation can be achieved. Moreover, it is also necessary to conduct

coordinative preemptive action between stakeholders and users with regard to groundwater management based on the existing potential.

With regard to the identification and formulation of the problem, the aim of this current study is to investigate and create the mapping of groundwater catchment system based on the geological condition of the faults in Semarang city.

II. LITERATURE REVIEW

A. Groundwater Catchment System Concept

The infiltration wells is a construction which can be used as a groundwater circulation media, with the aim of keeping the groundwater volume as well as to control floodwater (Bras 1990; Chow, 1988; Gupta, 1989; Ponce, 1989, Viemann, 1977). The discussion about infiltration well is always associated with groundwater, which is the flow inside ground and are located in spaces between grains of soil constituent and in cracks of rocks. The basic concept of infiltration wells is giving a chance and way for the rainwater which drops on the roof or waterproof land to infiltrate the soil by collecting the water inside catchment system (Harsono, 2001). It is different to the conventional way in which rain water is let go or discharge to the river which then to the sea. This infiltration wells is an empty well with quite big capacity to collect rainwater before it infiltrates the soil (Hudson, 1971; Kirby 1980). Due to the infiltration wells, rain water has enough time to infiltrate the soil so that its catchment is optimal (Suripin, 2003).

B. The condition of Semarang City

Semarang City is illustrated in Figure 1, it is located on $6^{\circ} 50' - 7^{\circ} 10'$ South, $109^{\circ} 50' - 110^{\circ} 35'$ East. According to its administrative border, Semarang is bordered by the Java Sea on the north, by the Semarang regency on the south, by the Kendal regency on the west and Demak regency on the east. Based on its topography, the northern part up to the coastal area is lowland, whereas, the southern part is hills. Semarang with an area of $373,3 \text{ km}^2$ is inhabited by 1.763.370 people (Khumaedi, 2013). The increasing number of residential and population results in the 10% increase on the needs of clean water each year (2009 – 2015). The rainwater utilized in this city is approximately 40% and the rest is discarded to the sea.

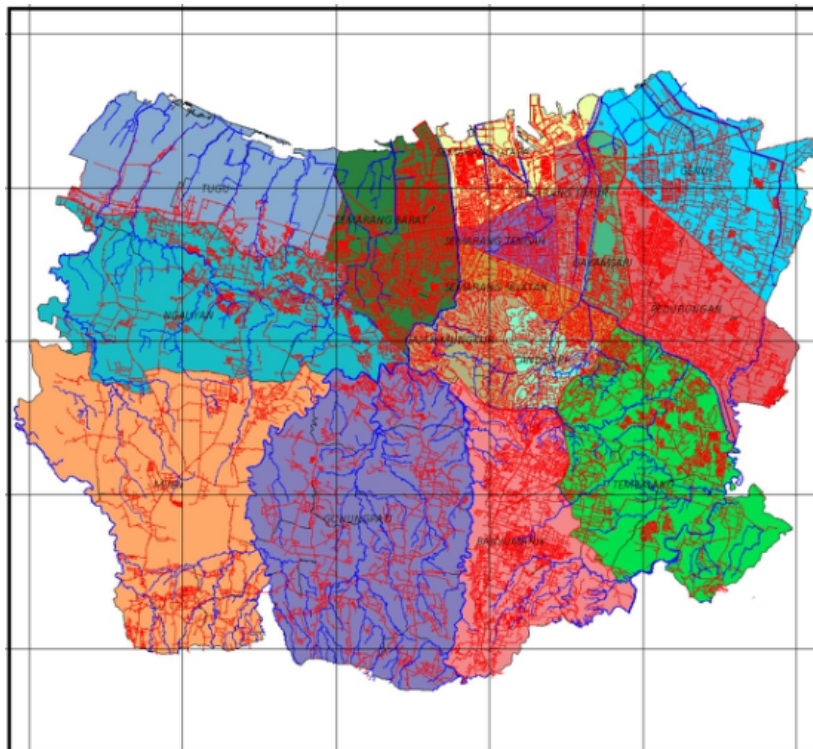


Figure 1. The Administrative Area of Semarang City as an object of the research location.

C. The condition of Semarang City

Hydraulic analysis on the infiltration well is necessary as an alternative on solving the problems related to the flow of the groundwater in the well (Krussemen, 1970). It is related to the system of existence, availability, capability, and the groundwater function.

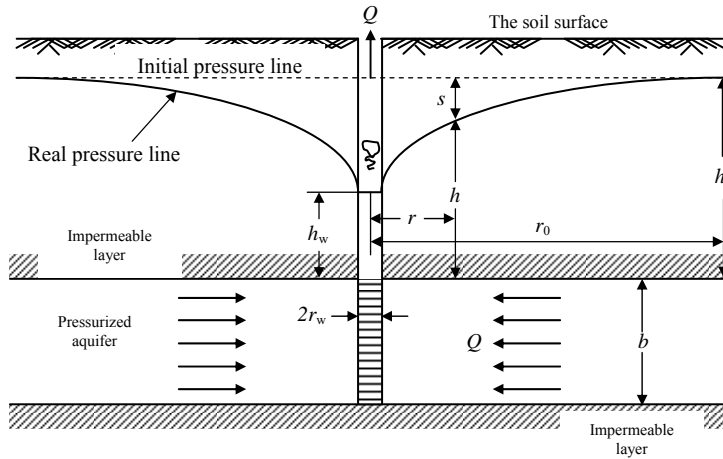


Figure 2. Pressurized Aquifer with the Steady Flow and Uniform Thickness (Todd, 1990)

The equation of the water debit flowing to the well on the balance condition can be written as follows (Todd, 1990) :

$$Q = A \cdot V = (-2\pi r_b) \left(K \frac{\partial h}{\partial r} \right) \dots\dots\dots 1$$

where Q is discharge (m³/s) in steady flow condition, A is area (m²), K is permeability coefficient (m³/day/m²) and V is volume (m³).

The condition restriction on the well $h = h_w$ and $r = r_w$, and the edge $h = h_0$ dan $r = r_0$

$$h_0 - h_w = \frac{Q}{2\pi K b} \ln \frac{r_0}{r_w} \dots\dots\dots 2$$

where h_0 is initial phreatic distance up to impermeable layers, h_w is inside phreatic distance up to impermeable layers, r_0 is radius of well, r_w is radius of well and b is the width of channel (m)

The equation of occurring pressure line:

$$h_w = h_0 + \frac{Q}{2\pi K b} \ln \frac{r_0}{r_w} \dots\dots\dots 3$$

so the equation can be written as follows:

$$Q = 2\pi K b \frac{h_0 - h_w}{\ln r_0 - \ln r_w} \dots\dots\dots 4$$

Those equations apply at constant suction and steady flow conditions.

III. RESEARCH METHOD

A. Selection of Study Sites

This study was conducted on 82 points covering the entire area as illustrated in Figure 3. Many technical and logistical factor influence the selection of study site. If the point of study site doesn't allow for measurement then adjustment was implemented on the point, thus enabling a shift on the coordinate of the initial point. A shift had to occur on several points due to its impossibility to do measurement, for example small field span, permanent building on the site, the topography of the field which is steep and etc. Some considerations were used in using the data of the study availability of high quality of field reconnaissance data and experienced investigator who carried out this work. Not all locations had the quality data especially related to the soil stratification, hydrological aspect and geological characteristics. The process of field data selection is necessary in order to obtain comprehensive results as the reference for the interpretation of location suitable for the water catchment area.

The data used to analyze physical object were in the form of residential area of Semarang. The determination of sampling area was carried out by taking residential area located in Semarang. The study includes 16 districts in the city, which are the District Mijen, Gunungpati, Banyumanik, Elephant Mungkur, South Semarang, Candisari, Tembalang, Pedurungan, Genuk, Gayamsari, Semarang East, North Semarang, Semarang Central, West Semarang, Tugu, and Ngaliyan

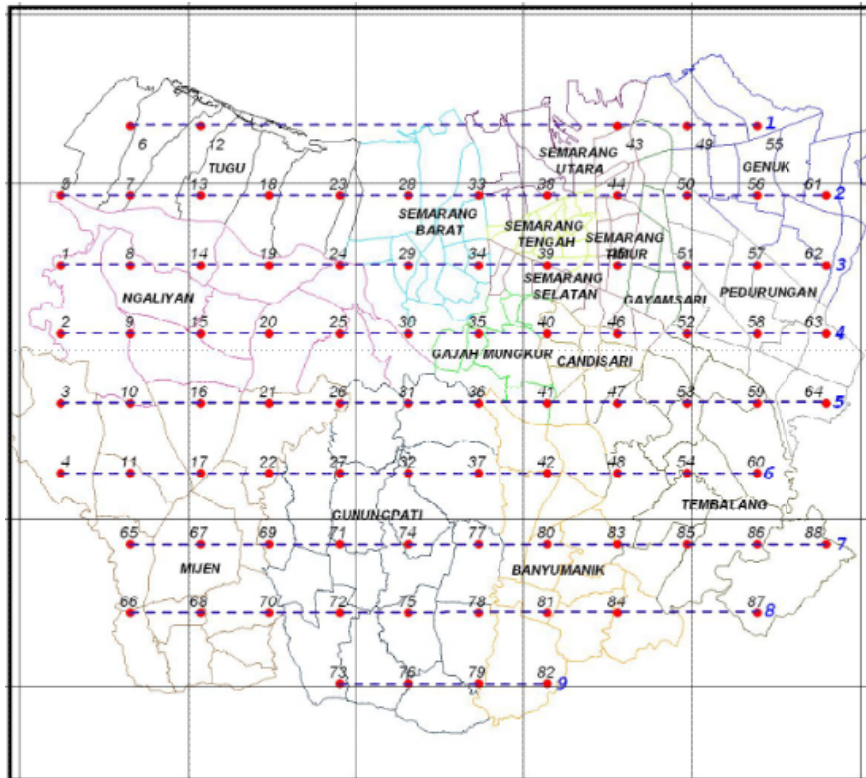


Figure 3. The study sites cover the entire territory of Semarang

B. Resistivitymeter Testing

The geoelectric measurement was conducted using *resistivitymeter*, consisting of current electrode made of stainless, potential electrodes made of copper, 400 meters of 2 rolls of cables with the length of 400 meters used for current electrode, 2 rolls of cables with the length of 60 meters used for potential electrodes.

A set of tool as illustrated on the figure 3 is resistivity meter type G-Sound (GL-4100), GPS (*Global Positioning Systems*), height gauge, and inclinometer. The injection time on the device ranges from 4 – 5 seconds. Controlled AB voltage : 0 - 400 V. AB current max : 100 mA. Volt meter range : 0 - 1000 V. Ampere meter range : 0 - 400 mA.

This study employed a series of *Schlumberger* geoelectric method, which is a series which is used to determine the the depth and thickness of the layer inwardly or vertically. The working principle is that one way electric current flows into the ground through 2 current electrodes plugged into the ground. The electric current flowing to the ground was measured using amperemeter. The potential changes in the soil due to the electric current was measured via two (2) pieces of the potential electrode plugged between the two current electrodes.



Figure 4. Resistivity meter type G-Sound

The current transmitter was connected to the ampere meter in series, whereas the volt meter directly measured the VMN voltage. The simple schematic of resistivity meter measurement can be seen in the figure 5 below.

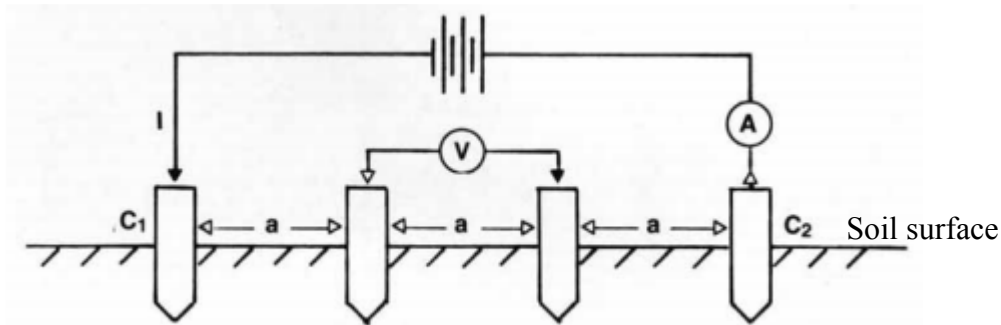


Figure 5. Schematic Structure of The Research Tools (Stanley, 1981)

IV. RESULTS AND DISCUSSION

A. The Results of Analysis on Points

The results of field measurement indicated that stratigraphically alluvium rocks spread from the western part up to the northern part of Semarang. On the center of this area, Measurement results showed that salt water is trapped between layers of clay and alluvium. Claystone and alluvium dominate the northern and western part of Semarang. Not to mention, the measurement results indicated the presence of geological fault that crosses from northern up to southern part of Semarang. The presence of geological fault will affect the direction of the water flow if the infiltration well is built in this area. Sand soil is identified in this area so that it can be estimated that rainwater falling in this area cannot experience maximum infiltration. The geological fault indicates that this area always moves although the movement is very small so that catchment area is built in this area then the direction of groundwater flow is impeded. Consequently, the groundwater catchment system will not work optimally.

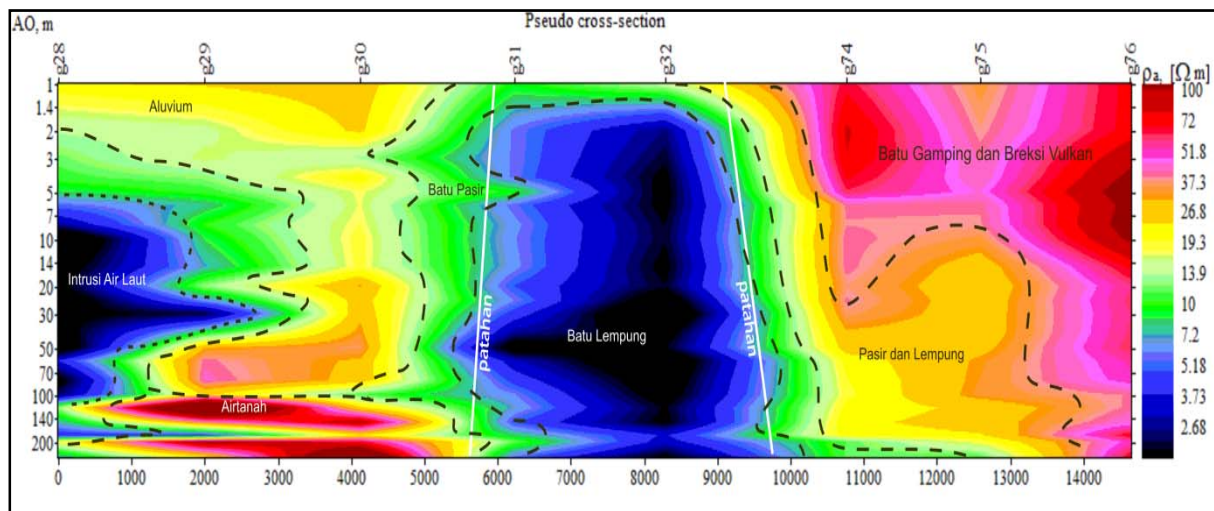


Figure 6. The Results of Cross Section on point

B. The Results of Analysis on Points 11-17-22-27-32-37-42-48-54-60

The cross section measurement points stretches from the western part to the eastern part of Semarang. The measurement results on the condition of soil stratification on the area can be seen on figure 6 which explains that the soil stratification of the western part consists of volcanic breccia, sand, and clay. The geological fault is found in the cross section with the conglomerate rocks dominating the area. The western and the eastern part of Semarang are dominated by sand and sand rock. A few volcanic breccia is identified on the western part of the city. The presence of sand rock and clay indicate that the site has the potential to function as catchment area. The presence of sand rock on an area is considered as the most supportive factor for an area to be declared as the groundwater catchment area due to its porous nature which enables water infiltrates the pores of the soil. The presence of geological fault is used as the boundary of groundwater catchment area so that rainwater infiltration can be stored optimally in the soil due to the impermeable properties of conglomerate rock.

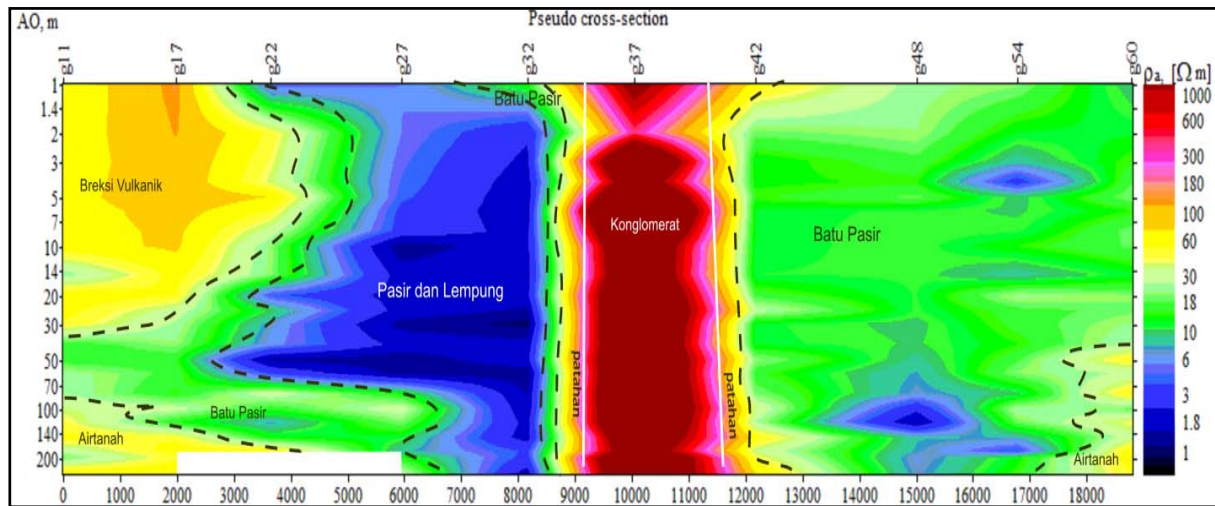


Figure 7. The Results of Cross Section on point 11-17-22-27-32-37-42-48-54-60

C. The Results of Analysis on Measurement Points 41-47-53-59-64

The cross section of measurement points which stretches from the middle part to the western part of Semarang can be seen on the figure 8. Figure 8 explains that stratigraphically measurement area consists of volcanic breccia rock, alluvium, sandstone and clay. The fault zone is located on one side of the city characterized by steep cliffs. The establishment of groundwater catchment system in this area will result in the increasing volume of rainwater or surface water permeating the soil. The increasing volume of water stored in an area with steep cliffs and fault zone can lead to landslide.

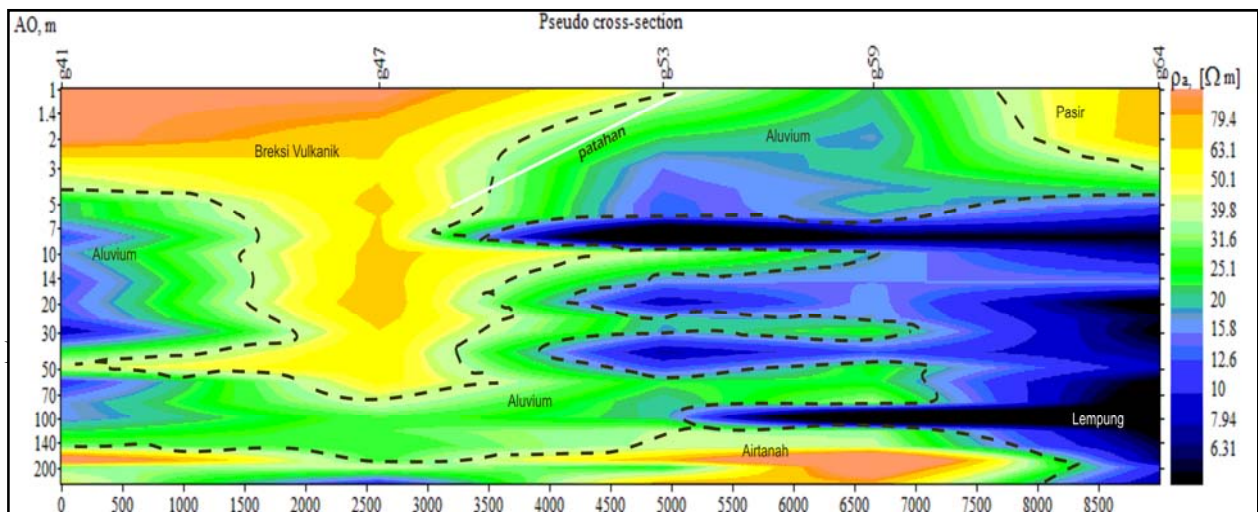


Figure 8. The Results of Cross Section on point 41-47-53-59-64

The results of cross – section analysis showed that generally area of Semarang is composed of 5 rock formations ,which are alluvium, volcanic breccia, clay, sandstone and sand, formed in the tertiary and quarter age,. The results of geoelectric analysis showed that there are 3 geological faults that intersect Semarang. The presence of the fault will affect the direction of groundwater flow from southern part to the northern part of Semarang.

The results of geoelectric analysis also revealed that there are 3 geological faults in some locations, in the southern and the middle of Semarang. The existence of such a fault indicates that there is little movement of the soil. The effect of the geological fault will change the direction of groundwater flow and this phenomenon must be considered in terms of site selection of water catchment system. Local basins are found in some locations which can be studied further on their potential as water catchment system.

V. CONCLUSION

1. In this present study, three regional faults have been identified in Semarang, namely Sukorejo, Tinjomoyo and Jangli fault. Those faults intersect the direction of groundwater flow from the south to the north towards the sea. Majority of the groundwater direction flows from south to north.

2. The analysis showed that some local basins were identified such as in the south and south west of Semarang, their flow direction is precisely on the opposite direction. This condition indicates that groundwater flow from the south will be impeded by the presence of the faults areas.

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