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Developing a Groundwater Conservation Zone in Jepara Groundwater Basin

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Abstract. Jepara groundwater basin has an area of about 545 km2. An increase in the number of residents accelerated the need for clean water. One circumstance to meet the needs of clean water is to utilize groundwater. Increasing groundwater utilization can result in damage to groundwater conditions and the environment. Therefore, it is necessary to conserve groundwater. The objective of this research was to prepare utilization and conservation zones and to conduct hydrogeological conditions and groundwater quality research in the area for recommendations of groundwater use. The methods were geological, and hydrogeological mapping included measurement of groundwater levels and groundwater sampling. Groundwater levels were measured via 150 dug wells, six springs and 16 artesian wells. The results determined the type of lithology in the form of tufa units, volcanic breccia, andesite and alluvium. Groundwater levels showed the direction of groundwater flow was from the southeast to the northwest. The pH value of artesian wells ranged between 6.70-9.19. There are four conservation zones in a confined aquifer, i.e. secured, vulnerable, critical and damaged.

Keywords: Groundwater basin, hydrology, quality

INTRODUCTION

Groundwater basins are areas that are bound by the hydrogeological process, a place where groundwater recharge, transmission and discharge processes happen. The research area was located in Jepara District, Central Java Province, Indonesia, which includes nine subdistricts, i.e. Donorojo, Keling, Kembang, Bangsri, Batealit, Pakisaji, Mloggo, Jepara and Tahunan. The Jepara groundwater basin boundary includes a groundwater divide type, a boundary which separates two groundwater flows with opposite directions. This boundary is located from the southeast at Mt. Muria to Donorejo in the north, also from the south at Mt. Muria to Awur Bay in the west. North-west area boundary includes an external surface water boundary type, which is seawater.[1]

The Jepara local groundwater basin has an area about 545 km^2. Along with the rapid development in the research area, population growth has also increased, this causes the need for clean water for various purposes to also increase. One way to fulfil the need for clean water is to utilize groundwater. Based on the Statistical Bureau of Jepara District Data for 2013, total population included in the research area was 563,866. With clean water estimation by Government for one person at 120 L/day, then clean water needed from the Jepara groundwater basin is estimated at 16.3 million m^3/day.[2] If groundwater is overexploited beyond its availability and there is lack of attention to its environmental, it may result in critical groundwater conditions and its environment, such as decreased groundwater quality and water level.[3]

Therefore, this research was done to cope with and anticipate further environmental degradation by performing groundwater conservation and utilizing zonation of the groundwater basin.[4] Determination of utilization and

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conservation zones includes secure, vulnerable, critical and damaged. This study aimed to determine the quality of groundwater for drinking water, to determine the conditions of groundwater utilization and to determine the recommendations of groundwater conservation. Fig. 1 shows the location of the Jepara groundwater basin, dug wells, springs and artesian wells.

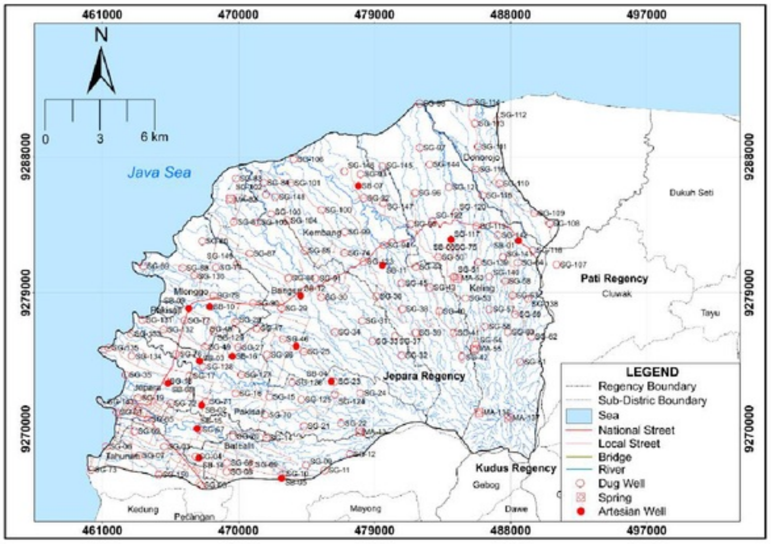

FIGURE 1. Location of Jepara groundwater basin.

MATERIALS AND METHODS

Based on the Geological Regional Map of Kudus,[5] there are various types of lithology in the research area. They can be grouped into several units of rock from the oldest to the youngest as follows: Muria Tuff Formation (Qvtm), Muria Lava Formation (Qvlm) and Alluvium (Qa), Fig. 2.

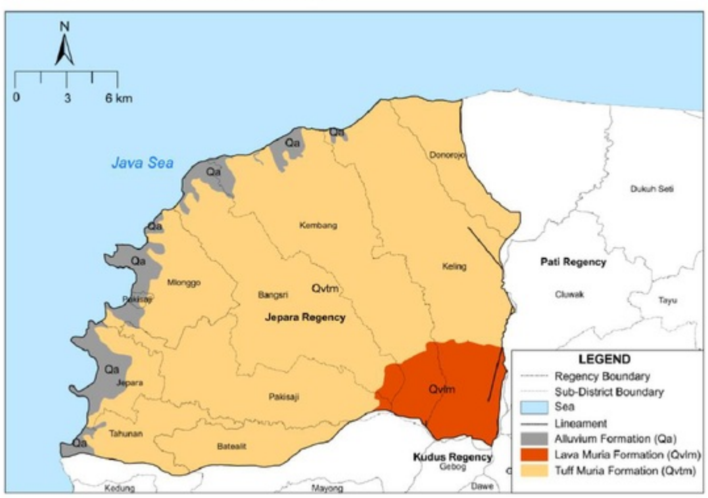

FIGURE 2. Regional geological of Jepara groundwater basin.

Jepara groundwater basin has three aquifer types based on lithology and groundwater relationship, Fig. 3, namely aquifer in which flow is intergranular, aquifers in which flow is both through fissures and interstices, and aquifers in which flow is through fissures.[6] Furthermore, these aquifers are divided into four subtypes, i.e. extensive and highly productive aquifers, extensive and moderately productive aquifers, locally productive aquifers and regions without exploitable groundwater.

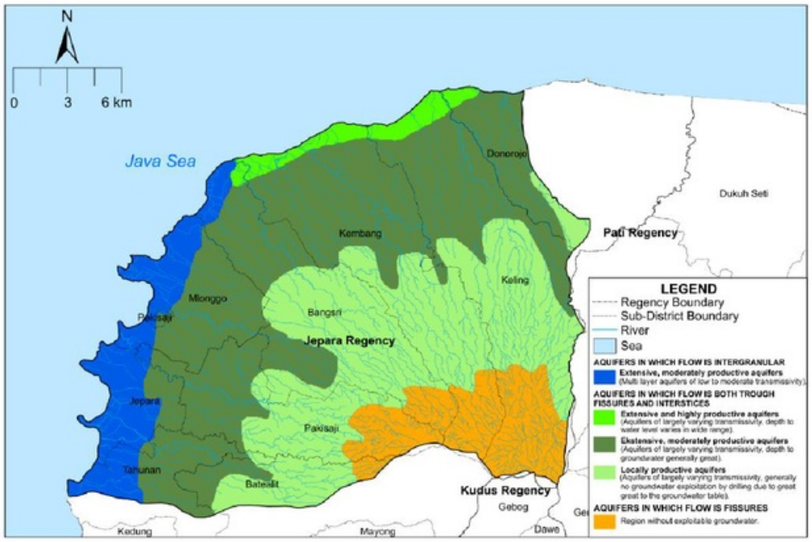

FIGURE 3. Hydrogeological map of Jepara groundwater basin.

Potential groundwater map in Jepara groundwater basin, Fig. 4, shows four areas of groundwater potential, i.e. moderate groundwater potential on an unconfined aquifer and high on confined aquifer, moderate groundwater potential on unconfined aquifer and moderate on confined aquifer, poor groundwater potential on unconfined aquifer and moderate on unconfined aquifer and region without exploitable groundwater potential on unconfined aquifer and moderate on confined aquifer.

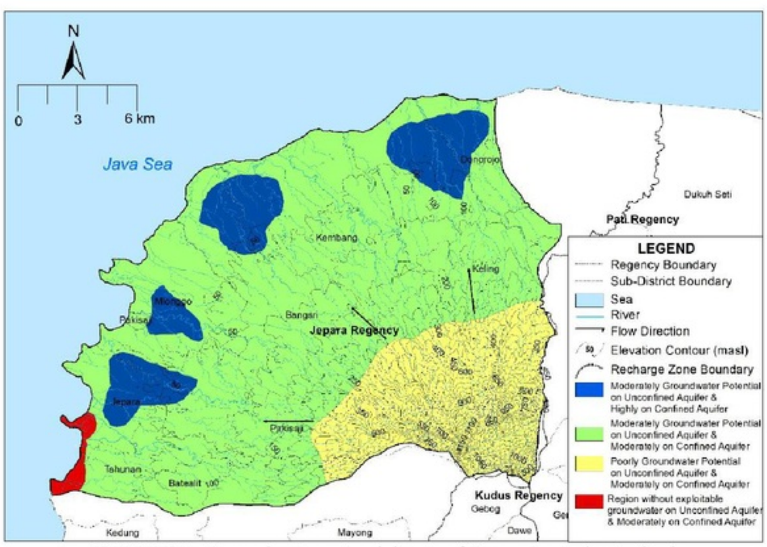

FIGURE 4. Groundwater potential map of Jepara groundwater basin.

Groundwater conservation is an effort to protect and maintain the existence, condition and environment of groundwater to preserve sustainability and/or continue availability in sufficient quantity and quality to meet the needs of living things both now and for the future.[7] Determination of conservation zones was conducted by combining the water table decline parameters (compared from 2013 to 2016), groundwater quality (conductivity from 2013 to 2016), groundwater potential, recharge zone and groundwater utilization map. Water level decline can be calculated with Equation 1:

$$s = \frac{p}{d} x100\% \tag{1}$$

With:
s: water table decline
p: decline in groundwater usage
d: water table from a confined aquifer.

Based on calculation of water table decline, the study area can be classified into four classes, i.e. secure if less than 40%, vulnerable (40-60%), critical (60-80%) and damaged (more than 80%). Groundwater quality is also considering as a parameter to determine the utilization and groundwater conservation zones, i.e. total dissolved solids (TDS) or electrical conductivity (EC).

Following consideration of the water table decline and its quality, and the presence or absence of land subsidence, the degree of damage to groundwater conditions and its environments can be determined based on the matrix in Table 1.

The groundwater conservation zone in a groundwater basin can be divided into two zones, namely groundwater protection zone and groundwater utilization zone. A groundwater utilization zone is a zone determined by its land capacity, the similarity of groundwater damage levels and similarity of its management. Groundwater protection zones cover groundwater recharge zones and spring protection zones.[8] Recharge and discharge zones can be determined by hydrogeological data identification such as slope, river pattern, spring and groundwater depth.

TABLE 1 Matrix to develop groundwater conservation zone

Groundwater Quality \ Water table decline	<40%	40%-60%	60%-80%	>80%	Land subsidence
TDS< 1,000 mg/L Conductivity < 1,000 µS/cm	Secure	Vulnerable	Critical		Critical
TDS 1,000–10,000 mg/L Conductivity 1,000–1,500 µS/cm					
TDS 10,000–100,000 mg/L Conductivity 1,500–5,000 µS/cm					
TDS>100,000 mg/L Conductivity>5,000 µS/cm Heavy metal and Hazardous and Toxic materials presence	Damaged				

RESULTS AND DISCUSSION

Groundwater Levels in a Confined Aquifer And an Unconfined Aquifer

The groundwater flow pattern and its direction in an unconfined aquifer in Jepara groundwater basin flowed from the southeast in the Mt. Muria area to the Java Sea in the northwest area, Fig. 5. It causes groundwater level of an unconfined aquifer to be deeper than in the lowland area. Meanwhile, the depth of piezometric level is around

14.5-30.5 m. The groundwater flows from the southeast to the northwest. The piezometric level in the north is up to 27 m above sea level, Fig .6

Based on hydrogeological mapping data of 150 dug wells, Table 2, the depth of the water table is from 0.5 to 21.5 m. Indeed, groundwater depth of the artesian wells, 16 wells, had a range from 14.5-30.5 m depth. Groundwater quality of dug wells based on pH and EC values had a range between 4.19-9.45 and

33.4-1,614.0 μS/cm, respectively. Artesian wells possess pH in the range from 6.70-9.19, while EC results were between 172-488 μS/cm, Fig. 7. Moreover springs samples (six samples) showed pH in the range 5.30-6.35 and EC in the range 53.2-168.0 μS/cm.

TABLE 2 Summary of physical and chemical groundwater samples data

Sample	EC(μS/cm)			pH			Groundwater depth (m)		
	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
Dug Well (150)	33.6	178	1,614	4.19	5.7	9.45	0.5	9.6	21.5
Springs (6)	53.2	98.1	168	5.3	6.35	6.9	-	-	-
Artesian Wells (16)	172	274	488	6.7	7.9	9.19	14.5	21.9	30.5

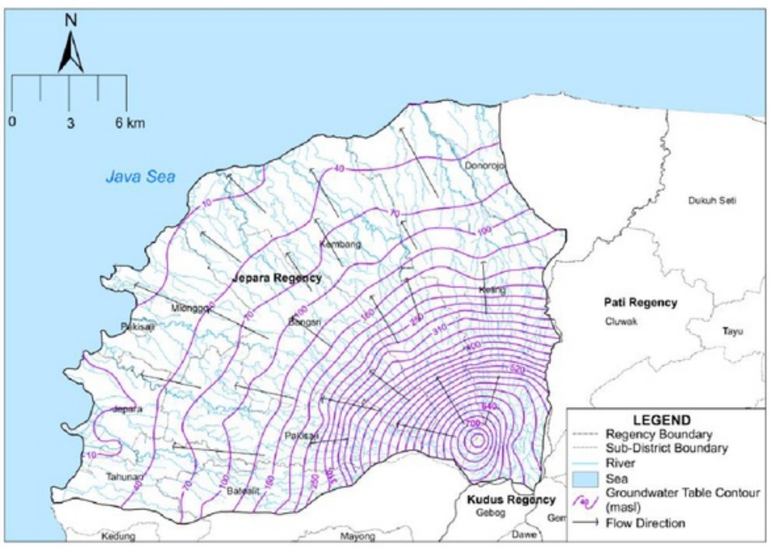

FIGURE 5. The water table map in 2016.

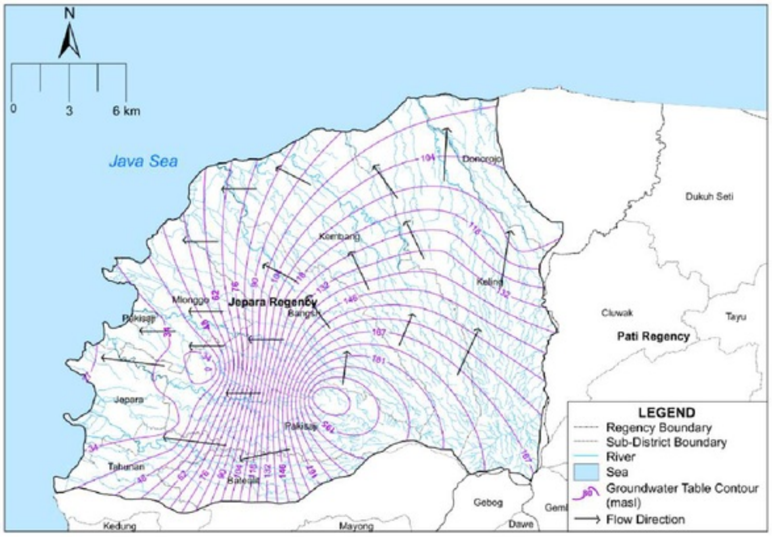

FIGURE 6. Map of piezometric level in 2016.

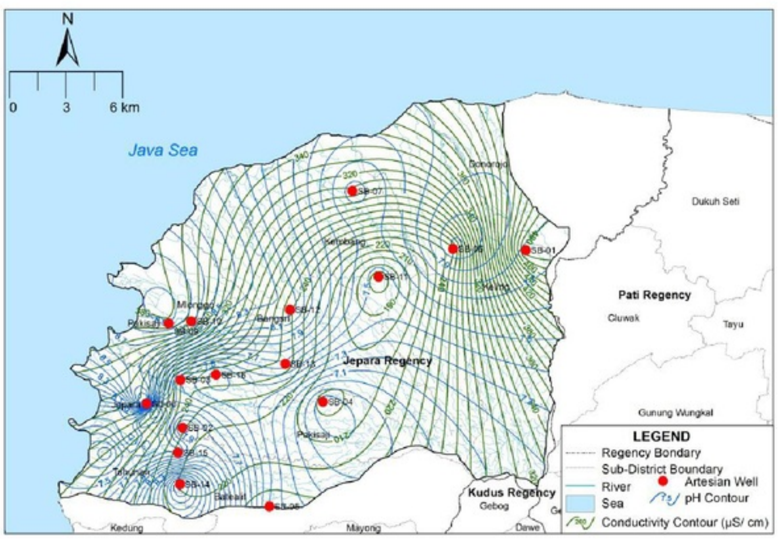

FIGURE 7 Groundwater quality map of artesian wells based on pH and EC value.

Groundwater Utilization

Groundwater utilization in the research area is mainly for domestic purposes, irrigation and by the local water company, Fig 8. Groundwater utilization for ponds can be found in the coastal area. These kinds of utilization lead to excessive groundwater exploitation.[9]

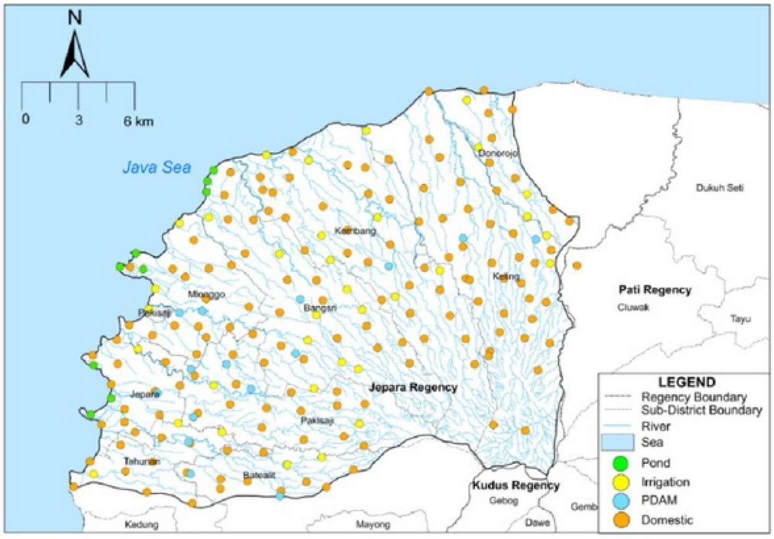

FIGURE 8. Groundwater utilisation map.

Groundwater Hazard Level

Water Table Decline

Based on the analysis of declining piezometric levels (piezometric contour in 2013 and 2016) using Equation 1, groundwater hazard level can be grouped into four zones, Fig 9, i.e.:

- Secure, shown as blue with 8% distribution in the research area
- Vulnerable, shown as green with 8% distribution in the research area
- Critical, shown as orange with 80% distribution in the research area
- Damaged, shown as red with 4% distribution in the research area

Water table decline occurred because of excessive groundwater exploitation.

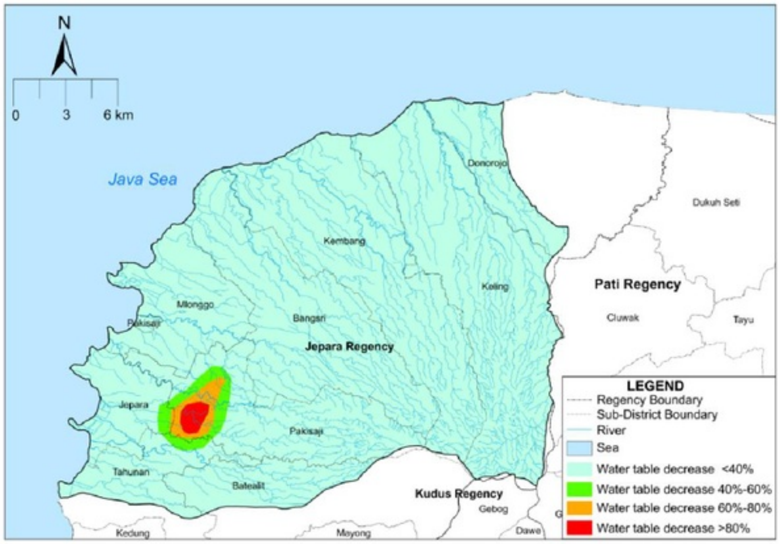

FIGURE 9. Map of declining piezometric in the research area.

Conservation Zone and Recommendations

Based on conservation zone analysis in the research area, the Jepara groundwater basin can be divided into four zones, Fig. 10:

Groundwater Utilization Zone

Utilization zonation was obtained by overlying water table decline and conductivity maps, then grouping according to Table 2. This zone can be divided again into four zones:

1. Secure zone

In this zone, groundwater is extracted from a confined aquifer system (40-120 m depth) only for the local water company and some factories with optimal debit (10.5-12.5 L/s/well). Recommendation is to keep groundwater in this zone from being degraded into vulnerable zones, they should be monitored for groundwater use and some artificial recharge wells developed.

2. Vulnerable zone

In this zone, groundwater utilization is from a confined aquifer system (41.7-120.0 m depth) only for local water company with optimal debit (2.42-4.92 L/s/well). The recommendation is to control the amount of deep groundwater extraction and developing some artificial recharge wells.

3. Critical zone

In this zone, groundwater utilization is for the local water company with optimal debit less than 2.42 L/s/well. Recommendations for this area are groundwater utilization monitoring, developing some artificial recharge wells and prohibition to develop new production wells.

4. Damaged zone

This zone occurs due to excessive groundwater extraction. The recommendations at damaged zones are developing artificial recharge zones to replenish aquifer content,[10] alternative water distribution, prohibition of production wells and reducing the amount of groundwater extraction at existing wells.[11]

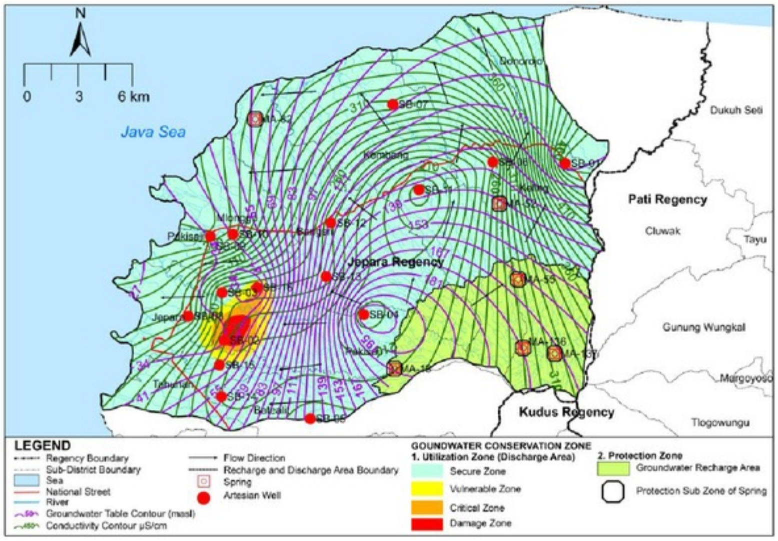

FIGURE 10. Map of groundwater utilisation and conservation zone.

Groundwater Protection Zone

1. Groundwater recharge zone
   Recharge zones were determined by slope, water table and groundwater quality map. Recharge zone was located at the southeast of the groundwater basin and the discharge zone located from the middle to upper area of the groundwater basin, Fig. 11. Groundwater recharge zones are vulnerable to contamination so land use must be considered.[12] To protect groundwater quality and quantity at discharge zones, this zone needs land use conservation, restrictions on the use of pesticide fertilizers, domestic waste disposal needs to be appropriately managed and maintenance of dam and irrigation networks.

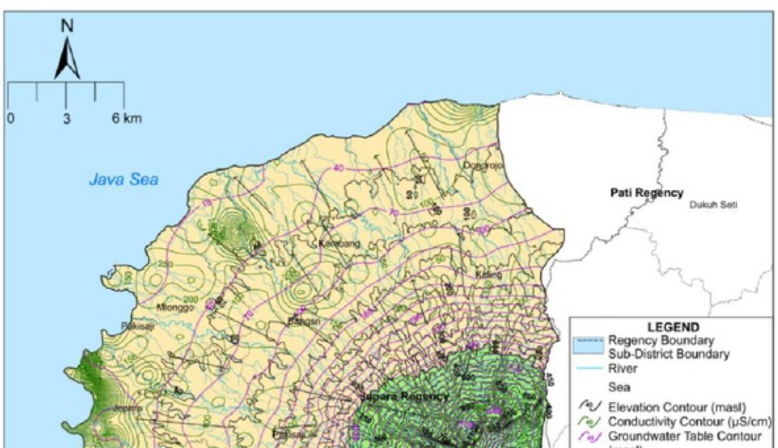

FIGURE 11. Map of groundwater recharge and discharge zone.

2. Spring protection zone
The area around the spring at the Jepara groundwater basin must be protected because if it is not protected it can affect quality and quantity of water and the physical condition of surrounding areas. Damaging activities such as drilling and excavation near the springs must be prevented and protected within a radius of 200 m from the occurrence of springs.[13]

SUMMARY

Based on a study of groundwater conservation and utilization zonation in the Jepara groundwater basin, it can be concluded that lithology of the research area consists of tuff, volcanic breccia, andesite lava and alluvium. From the analysis, groundwater conservation zones at Jepara groundwater basin are secure, vulnerable, critical or damaged zones. Groundwater protection zone consists of groundwater recharge zone and spring protection zone. Furthermore, the recommendations at vulnerable, critical and damaged zones like Pakisaji and Jepara subdistricts are reducing groundwater utilization, reducing extraction debit and prohibition of building new artesian wells.

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