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Application of Aquifer Vulnerability Index (AVI) method to assess groundwater vulnerability to contamination in Semarang urban area

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Abstract. An approach to assess groundwater to contamination is developing groundwater vulnerability map. Groundwater vulnerability is formulated as an intrinsic relative, the dimensionless property of a groundwater system that depends on its sensitivity to unfavourable human and natural impacts. Thus, to assess groundwater vulnerability to contamination in Semarang urban area is the objective of this research by using Aquifer Vulnerability Index (AVI). This method considered of two parameters related to the unsaturated zone, i.e. thickness (d) of each sedimentary layer in the unsaturated zone and Estimated hydraulic conductivity (K) of these sedimentary layers. There are five levels of groundwater vulnerability by using AVI method, i.e. extremely low, low, moderate/medium, high, and extremely high. The thinner the layer covers the aquifer, and the higher the value of the hydraulic conductivity of sediment layers will be increasingly vulnerable to pollution.

1 Introduction

Semarang, as an urban city and a capital city of the Central Java Province in Indonesia, is facing some environmental problems (e.g. declining groundwater level and its quality, land subsidence, seawater intrusion, and flooding) as an impact of groundwater overexploitation [1]. Without population and pollution management control, the amount of per capita safe water available for daily need is gradually reducing with time [2]. One technique to assess groundwater contamination is developing groundwater vulnerability map [3-7]. Thus, to assess groundwater vulnerability to contamination in Semarang urban area is the objective of this research by using Aquifer Vulnerability Index (AVI). Groundwater vulnerability can be formulated as an intrinsic relative, the dimensionless property of a groundwater system that depends on its sensitivity to unfavourable human and/or natural impacts. It means that groundwater vulnerability is combining a function of hydrogeological factors (e.g., aquifer characteristics and its properties in unsaturated zone) and human activities.

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2 Geologic and hydrogeologic setting

The study area is located in Semarang urban city. Geologic setting of Semarang consists of from the oldest to the youngest which are sedimentary deposits (Kalibeng Formation, Kerek Formation, and Damar Formation), volcanic product (Kaligetas Formation, Kaligesik Formation, Jongkong Formation, and Gajahmungkur Formation), and alluvium deposit [8]. The sedimentary deposits spread in the centre of Semarang. Kerek formation (middle Miocene age) consists of alternating claystone, marl and limestone. Claystone partly interlayered with siltstone or sandstone Kalibeng Formation (late Miocene-Pliocene) contains massive marl in the upper part, locally carbonaceous marls intercalating with tuffaceous sandstone and limestone. Damar Formation is mainly non-marine deposit consist of tuffaceous sandstone, breccia, conglomerate which is located in the centre of Semarang. The volcanic products are mainly located in the south of Semarang. They consist of breccia, lava, tuff and laharic breccia. Moreover, the latest deposits (Holocene, Lower Pleistocene) are in a marine environment form the coastal plain of Semarang. The bulk of the basin sediments contain alluvium (Qa). Alluvium is the result of surficial deposits from the coastal plain, river, and deltaic system deposits as shown in Figure 1.

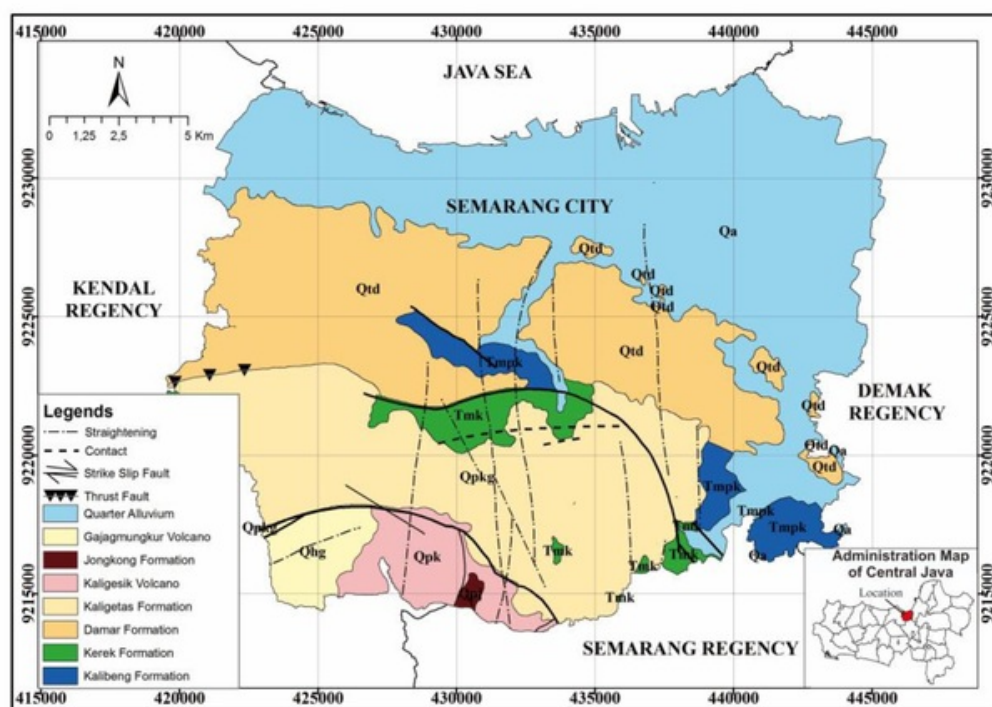


Fig. 1. Regional geological map of Semarang [3].

According to the regional hydrogeological map of Semarang [9], in the northern part, the aquifer is mainly flowing in the intergranular system. This system has the extensive aquifer with highly to the productive aquifer. The main lithology in this aquifer system is alluvial deposits. Meanwhile, in the south of Semarang, aquifer mainly flows both through fissures, and interstices which extensive spreading and moderately productive, but locally also available productive aquifer.

3 Methods

To assess groundwater vulnerability to contamination, Aquifer Vulnerability Index (AVI) method [10] was applied to protect groundwater. The AVI rating system model performed

7 for the evaluation of intrinsic vulnerability. This method considered of two parameters related to the unsaturated zone, i.e.

- i. Thickness (d) of each sedimentary layer in the unsaturated zone
- ii. Estimated hydraulic conductivity (K) of these sedimentary layers

The thickness of each sedimentary later was measured by levelling water level in some dug wells (around 308 wells) using water level indicator. Moreover, Geo-resistivity survey was applied to construct sedimentary layers. The resistivity of the rocks was measured by injected currents and the resulting differences at the surface [11]. There were around 46 locations to measure geo-resistivity in Semarang urban area. Since K values may not be visible for each sedimentary layer, a table of estimated values was required in the study area as shown in table 1 [10 &12]. The hydraulic resistance (c) that results from the product of the two parameters using the equation below gives the aquifer vulnerability index:

$$c = \Sigma d/K \tag{1}$$

Table 1. Hydraulic conductivity from various Sediment [10 & 12].

Sediment type	Hydraulic conductivity
Gravel	1,000 m/d
Sand	10 m/d
Silty sand	1 m/d
Silt	10 ⁻¹ m/d
Fractured till, clay or shale (0-5 m from ground surface)	10 ⁻³ m/d
Fractured till, clay or shale (5-10 m from ground surface)	10 ⁻⁴ m/d
Fractured till, clay or shale (10 m from ground surface, but weather based on colour, brown or yellow)	10 ⁻⁴ m/d
Sand – silt – clay (massive or mixed)	10 ⁻⁵ m/d
Massive till or mixed sand-silt-clay	10 ⁻⁶ m/d

Using equation 1 above, the groundwater vulnerability method using AVI can be generated from each geo-resistivity points. However, the calculated c or log c is related to Table 2 to define the vulnerability level.

5 **Table 2.** Relationship of Aquifer Vulnerability Index (AVI) to Hydraulic Resistance [10].

Hydraulic resistance (c)	Log (c)	Vulnerability
0 – 10	<1	Extremely high
10 – 100	1-2	High
100 – 1,000	2-3	Moderate/Medium
1,000 – 10,000	3-4	Low
>10,000	>4	Extremely low

4 Results and Discussion

Based on the hydrogeological mapping as shown in Figure 2, the minimum and maximum of groundwater depth, as unsaturated zones, are 0.03 m and 34 m respectively. Following the topography elevation, the minimum depth is found in the north to the east of Semarang, i.e. Genuk Sub-District while the deepest is located in the south-west and south-east of Semarang, i.e. Ngalian Sub-District and Tembalang Sub-District respectively. Figure 3 shows the class of groundwater depth. Five classes are less than 2 m, 2-5 m, 5-10 m, 10-20 m, and more than 20 m depth. The average groundwater depth is located in the centred of Semarang area that is 5-10 m.

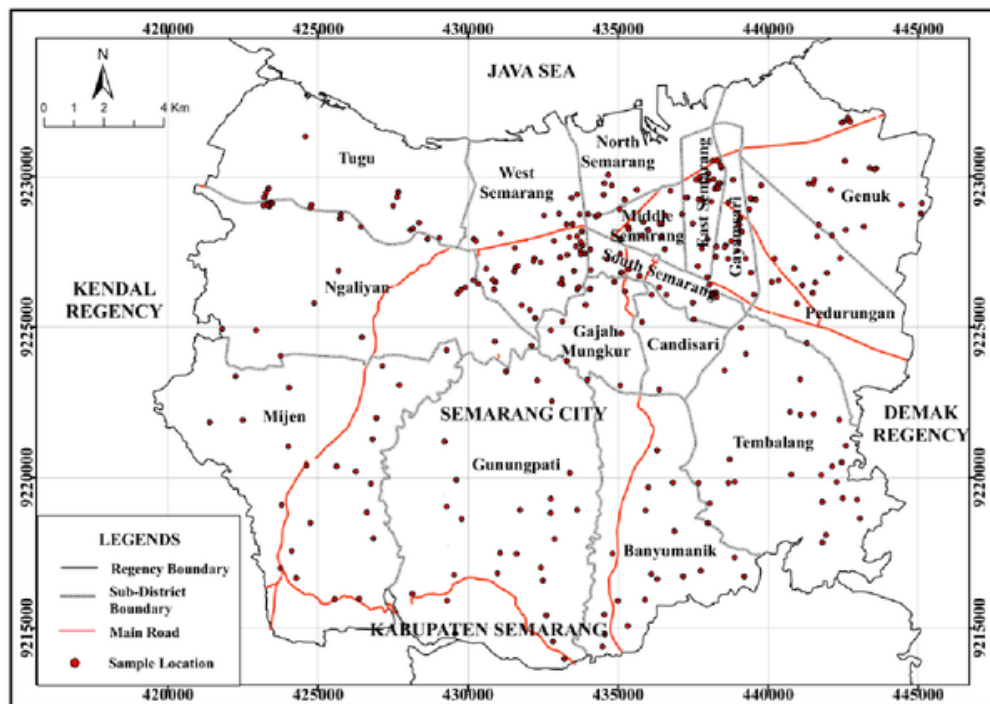


Fig. 2. Map of groundwater level measurement.

Based on the resistivity measurement, the subsurface consists of unconsolidated material/alluvium such as clay to sand, sedimentary rocks (sandstone, limestone, and claystone) and volcanic products (breccia, tuff breccia, tuff, tuffaceous sandstone, and lava). Alluvium is mainly located in the north and the east of Semarang whereas the sedimentary and volcanic rocks, are present in the centre and the south of Semarang. Thus, the hydraulic conductivity is the range 10^{-6} to 10^3 m/d. The highest hydraulic conductivity indicates excellent permeability, i.e. gravel to sand. Claystone is the lowest of the coefficient of permeability in the study area.

There are five levels of groundwater vulnerability by using AVI method (Figure 4), i.e. extremely low, low, moderate/medium, high and extremely high. Extremely low to low vulnerable zones describe that the thickness of unsaturated zones is in the range 10-20 m and above 20 m thick while the conductivity is very low (10^{-6} to 10^{-3} m/d). These areas are in Banyumanik, Gunungpati, and Ngalian Sub-District. This zone is located mainly in the south and west of Semarang.

The moderate/medium vulnerable has the unsaturated thickness of 5-10 m depth and the hydraulic conductivity 10^{-3} m/d. The area is located in the east of Semarang (locally Semarang Utara Sub-District and Genuk Sub-District).

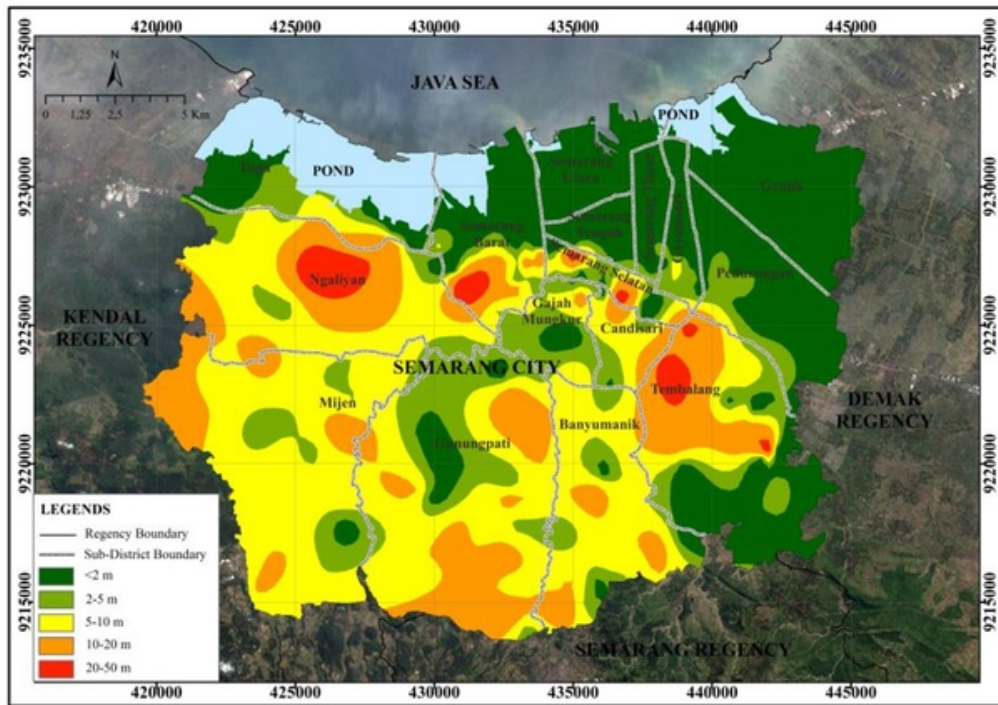


Fig. 3. Groundwater depth of Semarang urban area.

Moreover, the high to extremely high vulnerability zones are located in the west (Mijen Sub-District), the centre (Semarang Barat, Gajah Mungkur), in the north (Semarang Utara), in the east (Genuk) and the south-east (Tembalang) of Semarang urban area. The unsaturated zones are in the range 2-5 m and less than 2 m. The hydraulic conductivity is the range $10\text{--}10^3$ m/d.

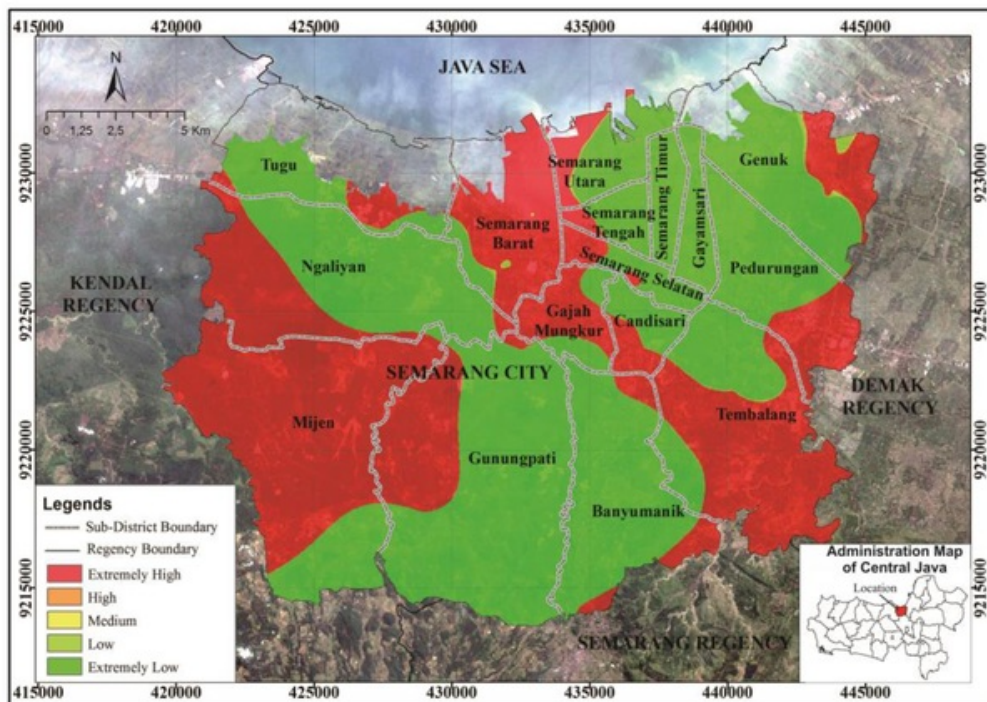


Fig. 4. Groundwater vulnerability map using AVI method.

5 CONCLUSIONS

Based on the AVI method, the thinner the layer covers the aquifer, and the higher the value of the hydraulic conductivity of sediment layers will be increasingly vulnerable to pollution. There are five levels of groundwater vulnerability to contamination in Semarang urban area, i.e. extremely low, low, moderate, high, and extremely high.

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