REVIEW

by Thomas Putranto

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Determining the Groundwater Vulnerability Using the Aquifer Vulnerability Index (AVI) in the Salatiga Groundwater Basin in Indonesia

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Abstract. Salatiga Groundwater Basin (SGB) is in the developing area of the Central Java Province/Indonesia which encounters groundwater pollution, and an assessment of the groundwater vulnerability to contamination is needed. This research aimed to define the level of groundwater vulnerability in the SGB. The aquifer vulnerability index (AVI) method was applied, which takes into account two parameters, the thickness of the rock layer, and the hydraulic conductivity. The thickness was then divided by the hydraulic conductivity to calculate the overall hydraulic resistance value. Those values were then interpolated to develop the groundwater vulnerability zone. The results highlight that the SGB has vulnerability zones to contamination that range from very low to very high.

Keywords: contamination, groundwater, pollution, vulnerability.

INTRODUCTION

Salatiga groundwater basin (SGB) is a groundwater basin with an area width of 287 km^2, covering three districts which include Semarang District, Boyolali District, and Salatiga city. The population in the SGB has grown every year, with 2011 the number of inhabitants in the SGB was 320,654 which then increased to 323,380 in 2014[1,2,3]. With a reasonably high population increase the need for freshwater also increased, and in fact, the availability of fresh water is currently insufficient. The availability of freshwater includes its quantity as well as its quality, which are affected by contamination due to human activity and excessive groundwater extraction. Therefore, groundwater vulnerability zone needs to be analysed.

Based on the regional geological map of Magelang-Semarang[4] and Salatiga[5], SGB consist of, from oldest to youngest, Kerek Formation (Tmk) Payung Formation (Qp), Merbabu volcanic stone (Qme), Sumbing's Lava (Qls), and Basal Formation (Qba). In addition, this area is dominated by Merbabu Volcanic Rocks that consist of breccia and tuff. This formation is found above the Kerek Formation basement and forms the lateral boundary of the SGB from the northeast to southeast. The Kerek Formation also forms the vertical boundary of the SGB as it consists of impermeable claystone. In the north region it coincides with the surface water boundary around Mt. Ungaran valley, while in the west and to the south it located around the Mt. Merbabu valley (Fig. 1).

Based on previous reaserch[6], the groundwater basin is an area that is bordered by hydrogeological boundaries due to hydrogeological activities like recharge, transmission, and discharge occurring. While groundwater is defined as the water inside the rock that moves through the fissure at various rocks layers[7], there is a relationship between precipitation around the basin and groundwater transmission, which is affected by physiography, surface geological condition, groundwater basin topography, and vegetation[8].

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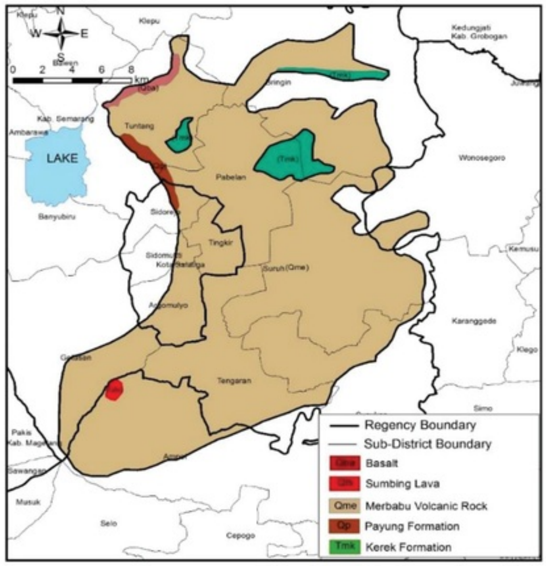


FIGURE 1. Geological Map of Salatiga Groundwater Basin.

The vulnerability of groundwater to contamination is a natural property of a groundwater system that depends upon the systems sensitivity to human activities' or natural changes. Groundwater vulnerability can be divided into two types[9]; the first is intrinsic vulnerability, whereby groundwater vulnerability to contamination is caused by natural effects like surface or underground geological condition, and the second is specific vulnerability, whereby groundwater vulnerability is caused by human activities such as land uses change, population density, and the amount of groundwater extracted.

There are several methods for mapping groundwater vulnerability zonation such as GOD, DRASTIC, and the aquifer vulnerability index (AVI.) Previous groundwater vulnerability zone research in SGB has been done by applying the GOD method[10], and the DRASTIC method[11]. The GOD and DRASTIC methods hinge on three and seven parameters, respectively. In addition to those methods, the AVI method is frequently applied by experts for small basin areas as a less sophisticated approach using a lesser number of indices. For example in Oasis Figuig, Maroko various zonations were generated from extremely low to extremely high vulnerability levels[12]. Moreover, the AVI method was applied to developing vulnerability to contamination in Densu Ghana River Groundwater Basin, where a high vulnerability zone was about 0.1%, while a moderate vulnerability zone was around 76%, and low vulnerability zone was up to 23.4%[13].

Thus, the objectives of this research were to develop groundwater vulnerability zones using the AVI method and compare the findings of the groundwater vulnerability zones using the other methods of GOD and DRASTIC. The purposes of this comparison was to determine the most suitable approach to analyze groundwater vulnerability to contamination in SGB and define the advantages and disadvantages of each method. Moreover, the AVI method can be a tool to evaluate the developing area in SGB based on a groundwater vulnerability assessment.

MATERIALS AND METHODS

The AVI method has been developed previously[14]. This method applies two parameters, i.e. rock thickness (d) above the aquifer, and hydraulic conductivity (K) from the rock. By applying these parameters, the hydraulic resistance (c) can be calculated using equation 1 below:

$$c = \sum_{i=1}^{i} \frac{d_i}{K_i} \qquad (1)$$

Value of the thickness and the overlaying lithology of the aquifer type can be derived from the borehole log data or electrical sounding results that are provide for the subsurface cross section of the area. Hydraulic conductivity (K) was determined by permeability tests of soil samples in the laboratory. Hydraulic resistance (c) value highlight the rockability of aquitard to transmit groundwater in a limited amount[15]. This value also shows an estimated time for contaminants to pass through the overlaying lithology of aquifer pores. The hydraulic resistance values that show the groundwater vulnerability level, as seen in Table 1.

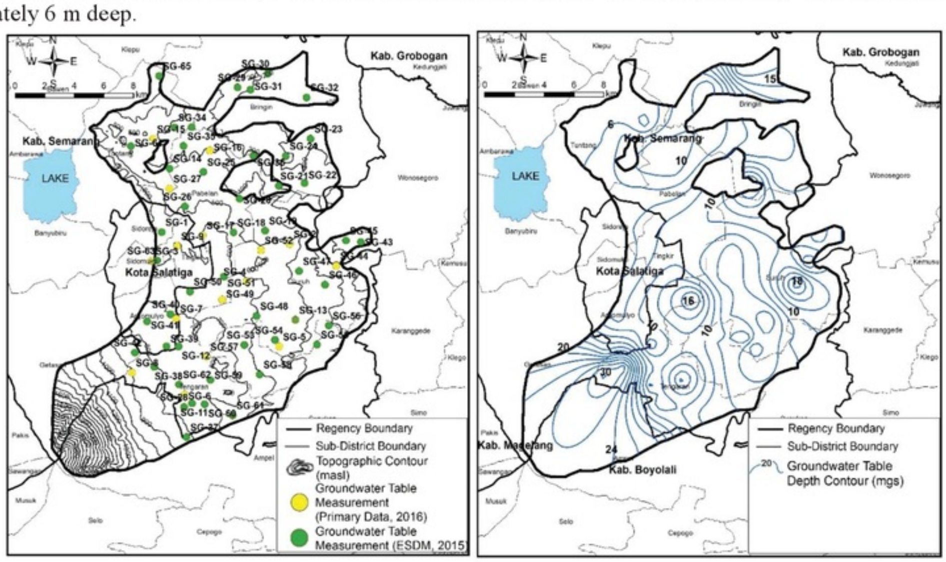
TABLE 1. Relation between hydraulic resistance value and groundwater vulnerability level using AVI method[14]

Hydraulic resistance (Years)	Log (c)	Vulnerability level
0-10	< 1	Very high
10-100	1-2	High
100-1,000	2-3	Moderate
1000-10,000	3-4	Low
>10,000	> 4	Very low

Hydraulic resistance values were interpolated by the software Surfer version 11 to provide hydraulic resistance values for all over the SGB. Furthermore, spatial analysis was applied using the software ArcGIS version 10.3 to obtain the groundwater vulnerability zone map.

RESULTS AND DISCUSSION

The AVI method works by overlaying the lithology of the aquifer thickness and the hydraulic conductivity of the overlaying lithology to acquire the groundwater vulnerability zone. The depth of the water table was measured from 82 dug wells in the SGB, with 65 wells measured in 2015 and 17 wells measured in 2016 (Fig. 2a). It was found that the depth of the groundwater had a depth range of 6 to 30 m (Fig. 2b). Furthermore, there are 10 additional locations to measure the overlaying lithology of the aquifer thickness in the SGB as seen in Fig. 3a. The groundwater was determined to be deeper in the higher topography, such as in LP 10 in the southwest of the research area compared to the Salatiga city centre (LP 5) (Table 2). Thus, the overlaying lithology of the aquifer was found to be very thick in the southwest at around 29 m deep. While in the city of Salatiga the overlaying lithology was the shallowest at approximately 6 m deep.



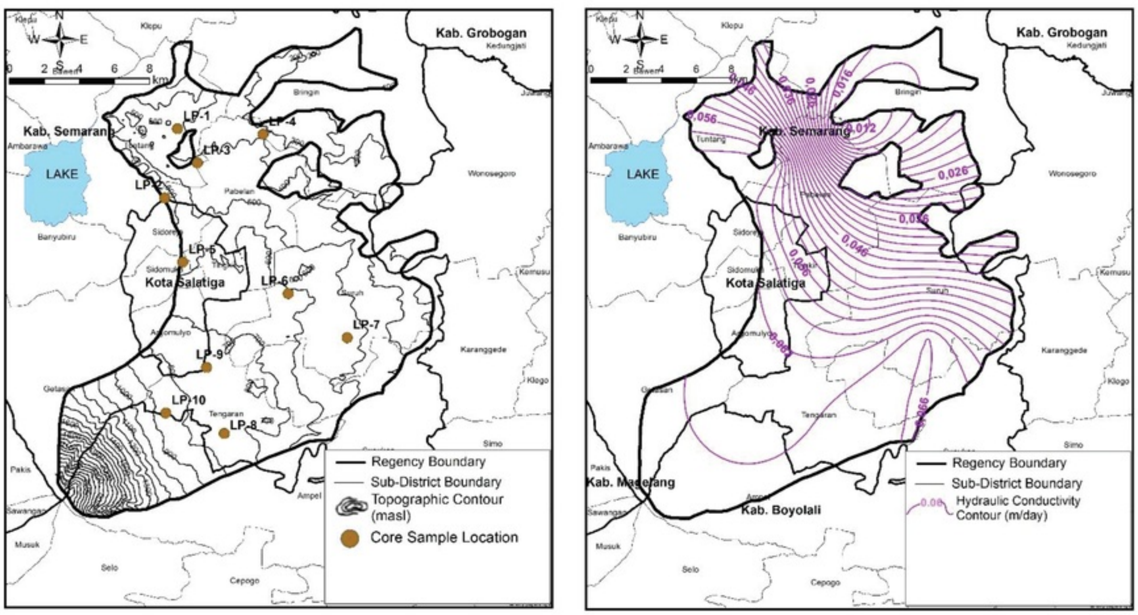
(a) (b)

FIGURE 2. a) Map of observation point in Salatiga Groundwater Basin b) Map of water table depth at the research area.

TABLE 2. Overlaying lithology of aquifer thickness

No.	Location	Thickness (m)
1	LP 1	8
2	LP 2	7
3	LP 3	10
4	LP 4	8
5	LP 5	6
6	LP 6	8
7	LP 7	15
8	LP 8	12
9	LP 9	12
10	LP 10	29

Based on the permeability test as shown in Table 3, the lithology consists of dominantly sandy red to brown clay. The value of hydraulic conductivity had a range of 1.8×10^{-2} m/day up to 6.7×10^{-2} m/day, as seen in Fig. 3b. It was found that the area of LP 2 in the west was the most permeable with hydraulic conductivity of up to 6.7×10^{-2} m/day. Whereas, the location of LP 4 which was close to the Kerek Formation had the lowest hydraulic conductivity at approxiamtely 1.8×10^{-2} m/day. This is most likely due to the Kerek Formation consisting of claystone and marl which are impermeable to water.



(a) (b)

FIGURE 3. a) Map of soil sample location at Salatiga Groundwater Basin b) Map of hydraulic conductivity contour at Salatiga Groundwater Basin.

Furthermore, the hydraulic resistance (c) was calculated using Equation 1 and then interpolated to develop the groundwater vulnerability to contamination in the SGB as seen in Fig. 4. Based on the map, the SGB is divided into 5 levels of groundwater vulnerability, from very low to very high. Very low vulnerability (> 10, 000 years) was found to have a distribution of approximately 5%, while low vulnerability (10, 000 – 100 years) was about 45%. Moderate vulnerability (100-1.000 years) was appoximately 25%, and high vulnerability (10-100 years) was about 10%. In the SGB, the very high vulnerability (<10 years) zone was determined to be approximately 15%. The highly vulnerable zone is located in the city of Salatiga to the east. It was recognised based on the distribution of dug wells which are very dense in the Salatiga city centre as shown in Fig 2a. Moreover, the groundwater depth was very shallow with a depth of only 3 m and the hydraulic conductivity was also very permeable up to 6 x 10^{-2} m/day. Thus, the hydraulic resistance of up to10 years means possible fast contamination of the zone. A very high vulnerable zone also occurs in the north of SGB, with the thickness of the overlying lithology relatively thin at only 8 m, while the hydraulic conductivity was also relatively permeable at around 5.4 x 10^{-2} m/day. Together these parameters lead to the contaminant being able to reach the saturated zone within 10 years. In addition, the high vulnerable zones are distributed locally in the northeast of the SGB, whereas the moderate level is spread throughout the east (Suruh area), the south (Tengaran), as well as locally in the northeast and northwest of the SGB.

TABLE 3. Hydraulic conductivity of soil sample test

No.	Location code	Lithology description	Hydraulic conductivity (m/day)
1	LP 1	Sandy clay, brown	$5.4x10^{-2}$
2	LP 2	Sandy clay, red	$6.7x10^{-2}$
3	LP 3	Sandy clay, brown	$6x10^{-2}$
4	LP 4	Greyish clay, stiff	$1.8x10^{-2}$
5	LP 5	Sandy clay, brown	$6x10^{-2}$
6	LP 6	Sandy clay, brown	$5.4x10^{-2}$
7	LP 7	Sandy clay, brown	$6.4x10^{-2}$
8	LP 8	Sandy clay, black	$6.4x10^{-2}$
9	LP 9	Sandy clay, brown	$6.3x10^{-2}$
10	LP 10	Sandy clay, brown	$6.3x10^{-2}$

The low level of vulnerability dominates the SGB at approximately 45%. The distribution of these zones is throughout the north and southwest. The low vulnerable in the southwest is mainly affected by the high topography which leads to the overlying lithology being at the thickest at approximately 29 m deep. While the very low vulunerability zones are located closed to the Kerek Formation, which would be the longest pathway for the contaminant to reach the groundwater.

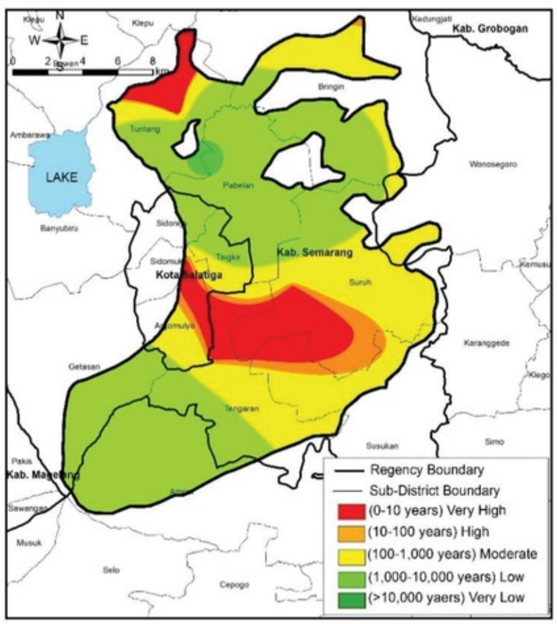
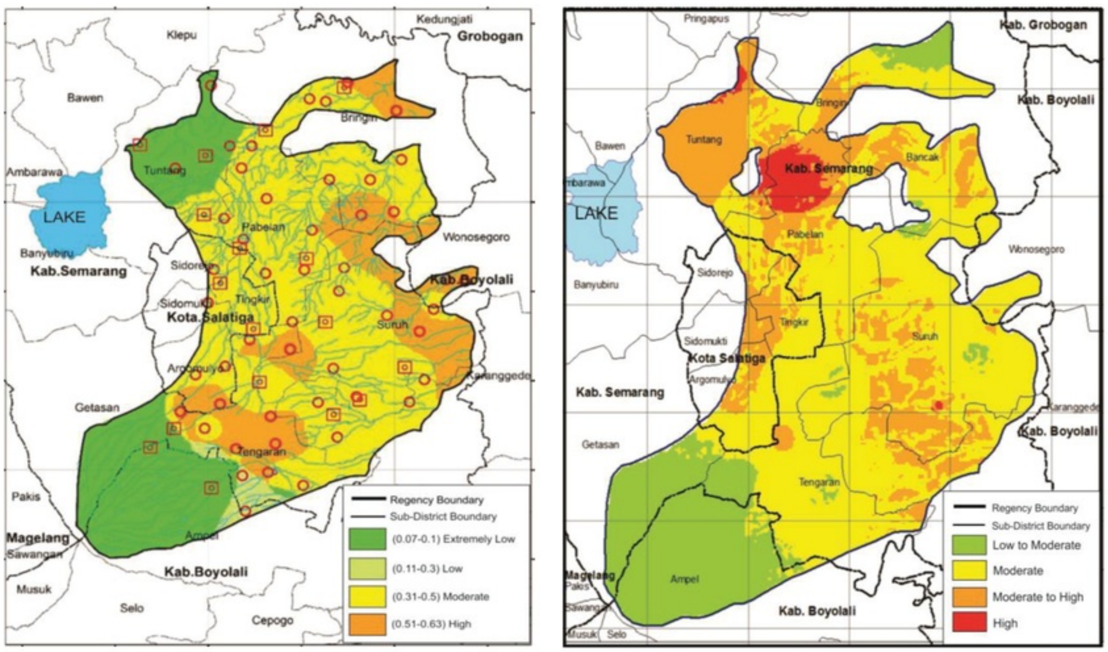


FIGURE 4. Map of Groundwater Vulnerability to Contamination using AVI Method.

Previous research into the groundwater vulnerability in the SGB was applied using the GOD method[10] and the DRASTIC method[11] as shown in Fig. 5a and Fig. 5b, respectively. The GOD method has a range of vulnerability levels from extremely low to high, it was found that the moderate level dominated in the SGB. Similiarly, the DRASTIC method also determines groundwater vulnerability from low to high levels, and in line with theGOD method, the DRASTIC method determined that the groundwater vulnerability to a contamination in the SGB to be at a moderate level. Contrary to both methods, the AVI method conduct in this study, very high vulnerable zones were found in the Salatiga city center and to the east. Moreover, the AVI showed the low level of vulnerability was more dominant in the SGB. The AVI has a range of vulnerable levels from very low to very high, which means the AVI vulnerabilities are remarkably sensitive to changes in their numerators (*d* values) and/or denominators (*K* values).

Based on this study comparing the GOD, DRASTIC, and AVI methods, it can be concluded that every method has some advantages and disadvantages (Table 4).



(a) (b)

FIGURE 5. Map of Groundwater Vulnerability to Contamination using GOD Method (a) and DRASTIC Method (b).

TABLE 4. Advantages and disadvantages of AVI, GOD, and DRASTIC methods

	Advantages	Disadvantages
AVI	• Very easy to apply in width area • Vulnerability level obtained based on the physical calculation • Requires only well log data • Can demonstrate a better hydraulic resistance change interval	• Not considering hydrogeological conditions • Not too accurate because of the ambiguous result

	Advantages	Disadvantages
GOD	• Very easy to apply to the width area with limited data • More detail compared to AVI method because of distinguishing confined aquifer and the unconfined aquifer have different properties	• Data availability very dependent on well log data and electrical sounding to understand the subsurface condition • Less accurate compare to the DRASTIC method because considering fewer parameters • Weighting system not through physical calculation, tend to be subjective
DRASTIC	• More accurate than AVI and GOD methods because considers more parameters • Used by more scientists in groundwater vulnerability mapping. The result is more convincing than AVI and GOD method due to more parameters used	• Some parameters are overlapping and making it less effective • Groundwater recharge value hard to calculate because evapotranspiration factor, rainfall, and runoff data challenging to obtain • Some experts still debate the slope or topographic slope parameters, and the existence of these parameters is not very influential • Weighting system in some parameters is subjective by some experts

CONCLUSIONS

In this study it found that the SGB has geological conditions such as Kerek Formation (Tmk) Payung Formation (Qp), Merbabu volcanic (Qme), Sumbing's Lava (Qls), and Basal Formation (Qba) and is dominated by Merbabu Volcanic Stone that consists of breccia and tuff. In addition, the Kerek Formation (Tmk) acts as a groundwater basin boundary because of its composition of impermeable claystone.

Based on the data analyses, the AVI method produced five levels of groundwater vulnerability in the SGB. The SBG was found to be dominated by low vulnerability zones at 45% of the total area. Compared to the GOD and DRASTIC methods, the AVI method has an advantage in calculating physical properties instead of weighting them.

It can be reccomended that consideration should be given to the very high vulnerability zones with routine control of groundwater quality needed to protect environmental degradation in the future. Furthermore, the government needs to be stricter in providing a new drilling well permission. Finally, it can be recommended that development for housing /andor industrial areas is possible in the low level vulnerability zones.

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REFERENCES

1. Statistics Indonesia – Boyolali, Kabupaten Boyolali dalam Angka (29 April 2015).
2. Statistics Indonesia – Semarang Regency, Kabupaten Semarang dalam Angka (10 October 2014)
3. Statistics Indonesia – Salatiga, Kota Salatiga dalam Angka (22 September, 2014).

4. R. E. Thanden, H. Sumadiraja, P. W. Richard. K. Sutisna and T. C. Amin, *Peta Geologi Skala 1:100.000 Lembar Magelang Semarang, Jawa Tengah* (Pusat Penelitian and Pengembangan Geologi, Bandung, 1996).
5. Sukardi and T. Budhitrisna, *Peta Geologi Skala 1:100.000 Lembar Salatiga, Jawa Tengah* (Pusat Penelitian dan Pengembangan Geologi, Bandung, 1992).
6. Minister of Energy and Mineral Resource of the Republic of Indonesia, Kementrian Energi Sumber Daya Mineral Republik Indonesia, *Cekungan Air Tanah di Indonesia*, (Ministry of Energy and Mineral Resource, Jakarta, 2017).
7. D. K. Todd and L. W. Mays, *Groundwater Hydrogeology* (John Wiley & Sons, New Jersey, 2005).
8. C. W. Fetter, *Applied Hidrogeologi* (4^{th} Ed.) (Prentice Hall, New Jersey, 2000).
9. C. A. Hatori, "Studi kerentanan intrusi air laut di Kota Semarang," Master Thesis, Gadjah Mada University, 2008.
10. M. Y. Rifai, "Kajian risiko kerentanan air tanah terhadap pencemaran pada akuifer tak tertekan cekungan air tanah (CAT) Salatiga, Provinsi Jawa Tengah," unpublished thesis (Semarang, 2016).
11. D. A. Kesuma, Studi kerentanan air tanah terhadap pencemaran di cekungan air tanah (CAT) Salatiga. Unpublished thesis (Semarang, 2017).
12. A. Jilali, Y. Zarhloule and M. Georgiadis, Arab J Geosci **8**, 1611-1621 (2013).
13. G. K. Anornu and T. J. Amos, Environ. Ecol **4**, 126-135 (2013).
14. D. van Stempvoort, L. Ewerd and L. Wassenaar, Can. Water Resour. J. **18**, 25-37 (1993).
15. G. P. Kruseman and N. A. de Rider, *Analysis and Evaluation of Pumping Test Data* (International Institute for Land Reclamation and Improvement, Netherlands, 2000).
16. K. Ronneseth, M. Wei and M. Gallo, *Evaluating Methods of Aquifer Vulnerability Mapping for the Prevention of Groundwater Contamination in British Columbia* (Province of British Columbia, 1995).

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