IOP Conf. Series: Earth and Environmental Science **70** (2017) 012008 doi:10.1088/1755-1315/70/1/012008

Factor weighting in DRASTIC modelling for assessing the groundwater vulnerability in Salatiga groundwater basin, Central Java Province, Indonesia

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Abstract. The increase in human population as well as area development in Salatiga Groundwater Basin, Central Java Province, will increase the potency of groundwater contamination in that area. Groundwater quality, especially the shallow groundwater, is very vulnerable to the contamination from industrial waste, fertilizer/agricultural waste, and domestic waste. The first step in the conservation of groundwater quality is by conducting the mapping of the groundwater vulnerability zonation against the contamination. The result of this research was groundwater vulnerability map which showed the areas vulnerable to the groundwater contamination. In this study, groundwater vulnerability map was assessed based on the DRASTIC Method and was processed spatially using Geographic Information System. The DRASTIC method is used to assess the level of groundwater vulnerability based on weighting on seven parameters, which are: depth to the water table (D), recharge (R), aquifer material (A), soil media (S), topography (T), impact of vadose zone (I), and hydraulic conductivity (C). The higher the DRASTIC Index will result in the higher vulnerability level of groundwater contamination in that area. The DRASTIC Indexes in the researched area were 85 – 100 (low vulnerability level), 101 -120 (low to moderate vulnerability level), 121 – 140 (moderate vulnerability level), 141 – 150, (moderate to high vulnerability level), and 151 – 159 (high vulnerability level). The output of this study can be used by local authority as a tool for consideration to arrange the policy for sustainable area development, especially the development in an area affecting the quality of Salatiga Groundwater Basin.

1. Introduction

Water on earth, either surface or groundwater, is very sensitive towards the changing in land utilization, especially the groundwater. The freshwater groundwater can be polluted by contaminants from human activity waste. The contaminants can be originated from agricultural, industrial, as well as domestic waste from the human settlement. Therefore, the decreasing quality of groundwater caused by contaminations needed to be urgently treated since almost half of the world's populations are still consuming the groundwater for drinking and other activities [1].

Salatiga groundwater basin is mostly located in the KEDUNGSEPUR (Kendal, Ungaran, Semarang, Salatiga, Purwodadi) area, which is one of the eight strategic areas included in the Central Java Province Spatial Plans (Rencana Tata Ruang Wilayah (RTRW)) Number 21 Year 2003 juncto Central Java Province Local Regulation (PERDA) Number 6 Year 2010, regarding the Central Java Province Spatial Plans. This area is planned to be the center of national economic growth for the local income equalization as well as to decrease the economic imbalance [2]. The Salatiga Groundwater Basin Area is also located on the strategic track which connecting the cities of Jogjakarta, Solo, and Semarang (JOGLOSEMAR). The strategic location of the Salatiga Groundwater Basin Area will open the opportunities to the development of the area, especially for the agricultural, trade and service, industrial as well as tourism sectors development [3].

The establishment of that strategic area was aimed to create the safe, comfortable, productive, and sustainable area so that the social, economic, and environmental aspects could be harmonized. However, its existence can provoke the uncontrollable population growth and land conversion, and thus will give rise to the environmental issues. As a picture, the land utilization in the City of Salatiga for the five-year range from 2010 to 2014, had undergone settlement sector development (increased for 120,40 Ha), trade sector development (increased for 4,48 Ha), industrial sector development (increased for 14,55 Ha), and non-agricultural area utilization. In general, the alteration of above land utilization was the conversion from non-irrigated agricultural land to mixed plantation land [4]. The alteration of land utilization to support the human activities, such as the settlement and industrial development, the usage of fertilizer for agriculture, the construction of the sanitary landfill, are the potential hazards which can influence the groundwater quality and increase the potency of groundwater contamination [5].

Thus, the assessment of aquifer vulnerability is very crucial to be conducted as the early attempt to protect the quality of groundwater. Zabet (2002) described vulnerability as the aquifer system sensitivity to be deteriorated caused by external influence [6]. The groundwater vulnerability concept is assuming that physical environment has the ability to protect the groundwater against the impact caused by the nature and human activities. The Earth materials can be acted a natural filter for the flowing through contaminants [7, 8].

The term ''vulnerability of groundwater to contamination'' was first used by Margat (1968). The groundwater vulnerability is used to the term natural protection against contamination. Groundwater vulnerability to contamination was defined by the National Research Council (1993) as ''the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer'' [9].

Many groundwater vulnerability assessment techniques had been developed in the last few decades, such as overlay and index method, statistics, as well as computer based process. Groundwater vulnerability assessment method used in this study was a DRASTIC Method. The DRASTIC Method is one of the overlay and index methods which can be broadly applied for several aquifers, such as basaltic rock, sedimentary rock, carbonaceous rock, hard rock, and coastal aquifers [1].

The objective of this research was to determine the aquifer vulnerability level against the contamination using the DRASTIC Method as well Geographic Information System to map the contamination-vulnerable areas in Salatiga Groundwater Basin.

2. Study Area

Salatiga groundwater basin is one of 19 groundwater basins across administrative areas regencies / cities in Central Java province. Administratively, most of Salatiga Groundwater Basin is included in the administrative area of Salatiga and Semarang regency as well as a small portion of Boyolali regency. Geographically, Salatiga groundwater basin is located approximately between 110° 27'56.81"-110°32'4.64" East longitude and 7°17'-7°17.23 'South Latitude with an altitude of 220 to 1,450 meters above Mean Sea Level. Salatiga groundwater basin lies mostly in the slopes of Mount Merbabu and small mountains, among others: Gajah Mungkur, Telomoyo, and Payung Rong [10]. The average annual Rainfall of the last 5 years is about 2,198.33 mm/ year [11, 12, 13].

Aquifer system at Salatiga groundwater basin is unconfined and confined aquifer. The rocks that make up the unconfined aquifer usually consisting of tuffaceous sandstone originating from volcanic activity of Mount Merbabu. In the southern part of the study area, the depth of the lower unconfined aquifer is at a depth of about 15-20 meters below local ground level surface, ie starting from the slopes of Mount Merbabu up toward the northeast. In the eastern part of the study area, the position of the bottom of the unconfined aquifer reaches a depth of 30 meters below local ground level surface.

The confined aquifer layer is composed of tuffaceous sandstone layers alternating with lahar and lava. Based on observations from some locations of spring, there are aquifer through the cracks. The confined aquifer is generally located at 43 up to 81 meters below local ground level surface on the slopes of Mount Merbabu and increasingly shallow eastward around the District of Wonosegoro. In the northern part of the research area, the upper confined aquifer depth is ranging from 18 meters below local ground level surface.

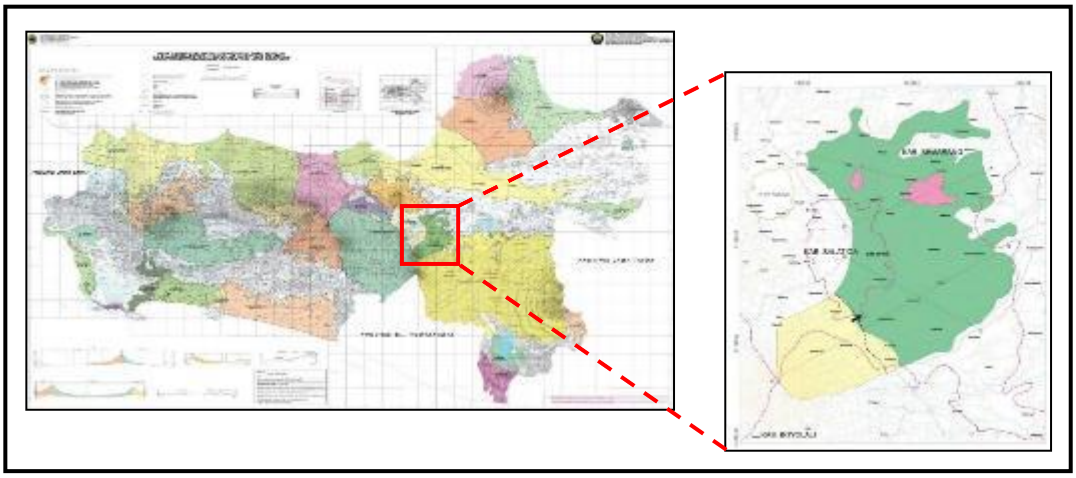

Figure 1. The location of study area.

3. Methodology

The DRASTIC Method of groundwater vulnerability level assessment uses seven parameters, which are: depth to the water level (D), recharge (R), aquifer material (A), soil media (S), topography (T), impact of vadose zone (I), and hydraulic conductivity (C). Depth to the water level data was taken from the depth measurements of the resident's dug wells in October-December 2016. Recharge Value was determined by considering the precipitation, evapotranspiration, and runoff levels in studied area between 2011 until 2015. Recharge level was calculated using meteoric water balance analysis. The aquifer materials, soil media, and impact of vadose zone parameters were obtained from the borehole correlation and interpretation log results as well as from geoelectrical survey results data taken from Energy and Mineral Resources Department of Central Java Province [10]. The topography of study area was prepared based on the Shuttle Radar Topographical Mission (SRTM) satellite data. While the hydraulic-conductivity data was obtained from the rock permeability tests in the study area. Each of the DRASTIC Parameters was weighted according to its level of importance, whereas each of the components from every parameters was rated based of its level of importance. Depth to the water table is weighted 5, recharge is weighted 4, aquifer material is weighted 3, soil media is weighted 2, topography is weighted 1, impact of vadose zone is weighted 5, and hydraulic conductivity is weighted 3. All seven parameters were then converted into digital format via Geographic Information System. By using ArcGIS 10.2, each of the components of the DRASTIC parameters were rated and weighted according to Aller,et.al., 1987 [14].

The next step was to calculate the DRASTIC Index using raster calculator with the formula below:

$$DI = Dr\,Dw + Rr\,Rw + Ar\,Aw + Sr\,Sw + Tr\,Tw + Ir\,Iw + Cr\,Cw \qquad (1)$$

With r = rating and w = weight.

The DRASTIC Index were classified into:

Table 1. Vulnerability Ranges Classification [15]

No	Vulnerability Level	DRASTIC Index
1	Very low	< 80
2	Low	80 - 100
3	Low to moderate	101 - 120
4	Moderate	121 - 140
5	Moderate to high	141 - 150
6	High	151 - 180
7	Very high	181 - 200
8	Extremely high	> 200

4. Result and discussion

4.1. Hydrogeologic Parameters

4.1.1. Depth to groundwater level. Depth to groundwater level is the minimum distance of ground surface from the water table. This is a crucial factor, since the condition of the depth to groundwater level will affect the time needed for the contaminants to reach the water table. The depth to groundwater level data was obtained from the measurements of 70 dug wells from October to December 2016. Depth to groundwater level was the shallowest at 1 meter below ground surface until up to > 30 meter below the local ground surface. The parameter of depth to groundwater level has a weight of 5 (Figure 2 and Table 2).

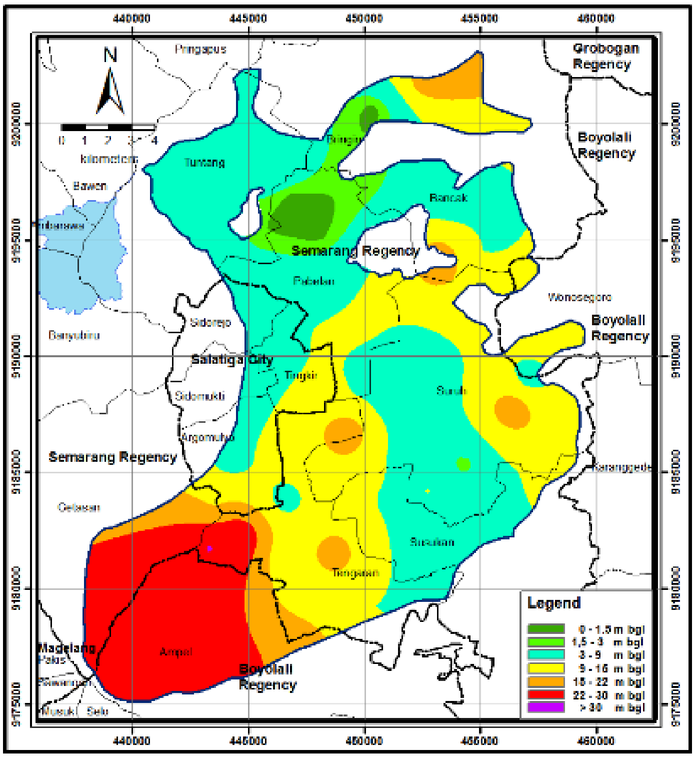

Figure 2. Depth to groundwater level.

Table 2. Value of depth to groundwater level.

No	Depth Interval (m)	Rating	Weight	Index
1	0 - 1.5	10	5	50
2	1.5 - 3	9	5	45
3	3 - 9	7	5	35
4	9 - 15	5	5	25
5	15 - 22	3	5	15
6	22 - 30	2	5	10
7	> 30	1	5	5

4.1.2. Net Recharge. The net recharge describes the amount of rainwater absorbed into the ground and reached the aquifer. The rainwater absorbed in the ground through the soil pores was assumed to be able to help transporting the contaminants vertically toward the groundwater level and horizontally inside the aquifer. Based on the calculation results, the recharge values of the studied areas, which were the recharge zone, were 0-51 mm/year, 52-102 mm/year, 103-178 mm/year, 179-254 mm/year, and 254-1,092 mm/year. The recharge parameter was weighted 4. The parameter score measurement, recharge amount and recharge parameter map can be viewed at Table 3 and Figure 3.

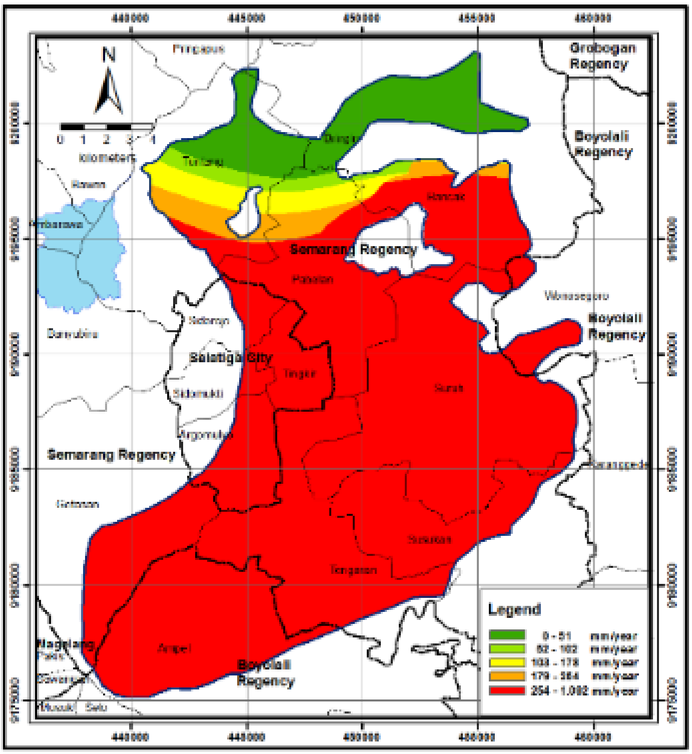

Figure 3. Net recharge.

Table 3. Score Measurement for Recharge Parameter.

No	Recharge (mm/year)	Rating	Weight	Index
1	0-51	1	4	4
2	52-102	3	4	12
3	103-178	6	4	24
4	103-178	8	4	32
5	254-1092	9	4	36

4.1.3. Aquifer Media. Aquifer media type has a role in controlling the movements of the contaminants inside the water saturated rocks (aquifer). The rocks assembling the aquifer in the study area were from Merbabu volcano. Based on the correllation results via drilling data and subsurface estimation with geoelectrical method, the type of rocks functioned as an aquifer was interpreted as Tuffaceous Sandstone Alternate with Volcanic Breccia and Fractured Andesite Lava. Aquifer media parameter weighted 3. The aquifer media measurement and the distribution maps can be seen in Table 4 and Figure 4.

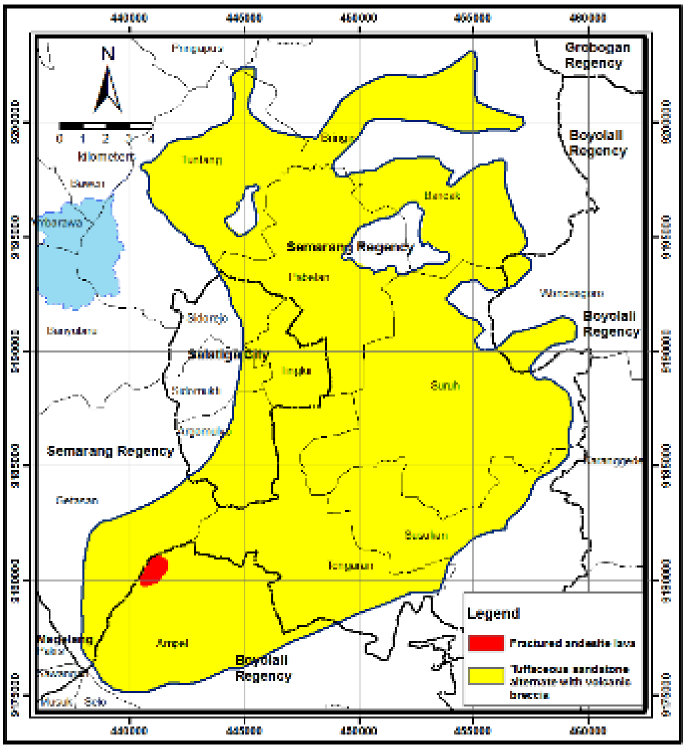

Figure 4. Aquifer Media

Table 4. Score Calculation for the Aquifer Media Parameter

No	Aquifer Media	Rating	Weight	Index
1	Tuffaceous Sandstone Alternate with Volcanic Breccia	6	3	18
2	Fractured Andesite Lava	3	3	9

4.1.4. Soil Media. Soil media is the uppermost of the unsaturated water zone which not undergone weathering. Based on the field observation and the soil permeability value of some soil samples in the study area, it can be interpreted that the soil media consisted of sandy loam and sand. Soil media parameter was weighted 2 points. The calculation of soil media parameter score as well as the distribution maps of soil media parameter can be viewed in Table 5 and Figure 5.

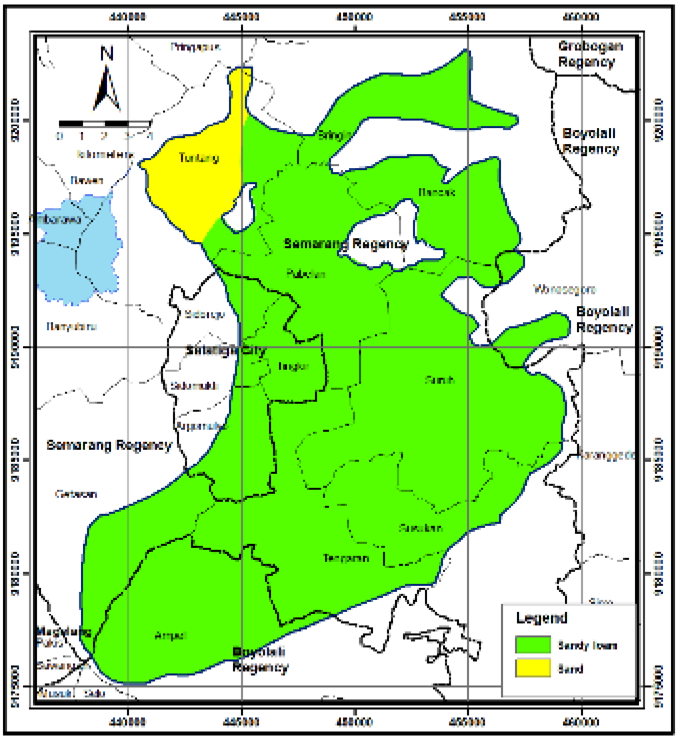

Figure 5. Soil Media.

Table 5. The Calculation of Soil Media Parameter Score.

No	Soil Media	Rating	Weight	Index
1	Sandy Loam	6	2	12
2	Sand	9	2	18

4.1.5. Topography. Steepness of an area which allows low slope for high infiltration of pollutant along with rainwater and steep slopes for low infiltration. The topography of study area was prepared based on the Shuttle Radar Topographical Mission (SRTM) satellite data [16]. Based on the slope maps, the studied areas have varies slope between 0 until > 18%. Slope parameter was weighted 1 point. While the Slope Distribution based on the interval and the score calculation for the slope can be seen on Table 6 and Figure 6.

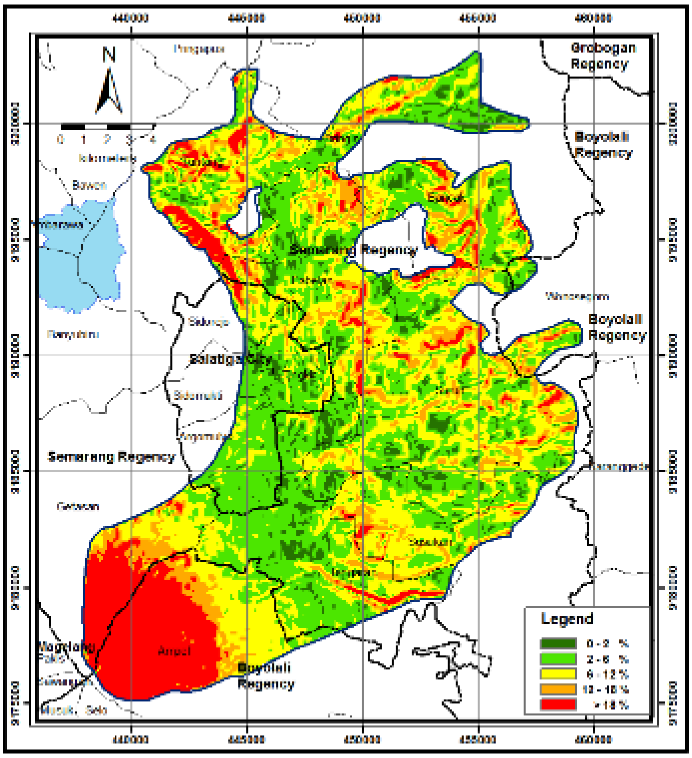

Figure 6. Topography.

Table 6. Slope Value.

No	Slope (%)	Rating	Weight	Index
1	0 - 2	10	1	10
2	2 - 6	9	1	9
3	6 - 12	5	1	5
4	12 - 18	3	1	3
5	> 18	1	1	1

4.1.6. Impact of Vadose Zone. The Vadose (unsaturated) zone is the zone located above the groundwater level. Based on the subsurface data according to the borehole log and geoelectrical data obtained from the Central Java Province Energy and Mineral Resources Department, it can be interpreted that the rocks on the water unsaturated (vadose) zone generally composed by sand and gravel with silt and clay content. Those materials resulted from the weathering of tuffaceous sandstone alternate with volcanic breccia. This parameter was weighted 5 points. The calculation of water unsaturated zone score as well as the distribution maps of that parameter can be viewed in Table 7 and Figure 7.

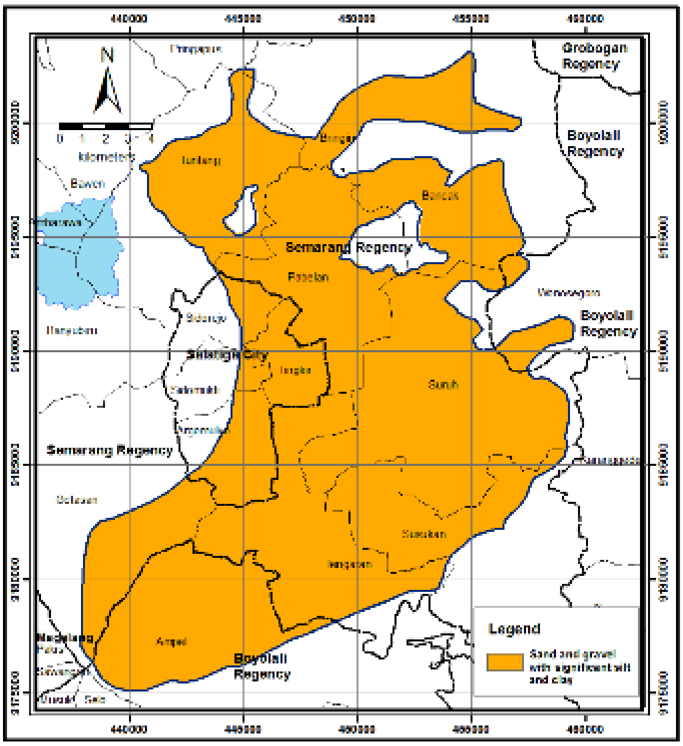

Figure 7. Vadose zone media

Table 7. The Calculation of Vadose Zone Media Parameter

No	Vadose zone media	Rating	Weight	Index
1	Sand and gravel with significant silt and clay	6	5	30

4.1.7. Hydraulic Conductivity. Hydraulic conductivity is the ability of the aquifer to transmit the water and to control the average speed of groundwater flow. Groundwater flow velocity also controls the speed of transport of contaminants in the aquifer. The hydraulic-conductivity data was obtained from the rock permeability tests in the study area. This parameter was weighted 3 points. The calculation of hydraulic conductivity score as well as the distribution maps of that parameter can be viewed in Table 8 and Figure 8.

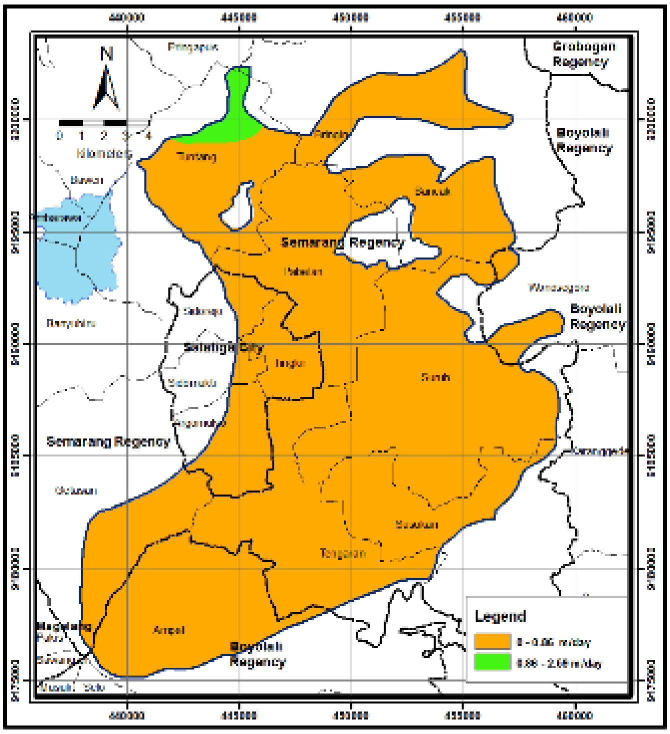

Figure 8. Hydraulic Conductivity

Table 8. The Calculation of Hydraulic Conductivity Parameter

No	Hydraulic Conductivity (m/day)	Rating	Weight	Index
1	0 – 0,86	1	3	3
2	0,86 – 2,59	2	3	6

4.2. DRASTIC Vulnerability Assessment

In this study, the minimum value of DRASTIC Vulnerability Index in Salatiga Groundwater Basin was 85 – 159. The values of DRASTIC Vulnerability Index were classified into five vulnerability levels, which are: Low (85 – 100), Low to moderate (101 – 120), Moderate (121 – 140), Moderate to High (141 – 150), and High (151 – 159). Here is the division of the groundwater vulnerability based on the calculation according to the weight of each parameter and rating applied (Table 9) along with a map of groundwater vulnerability (figure 9).

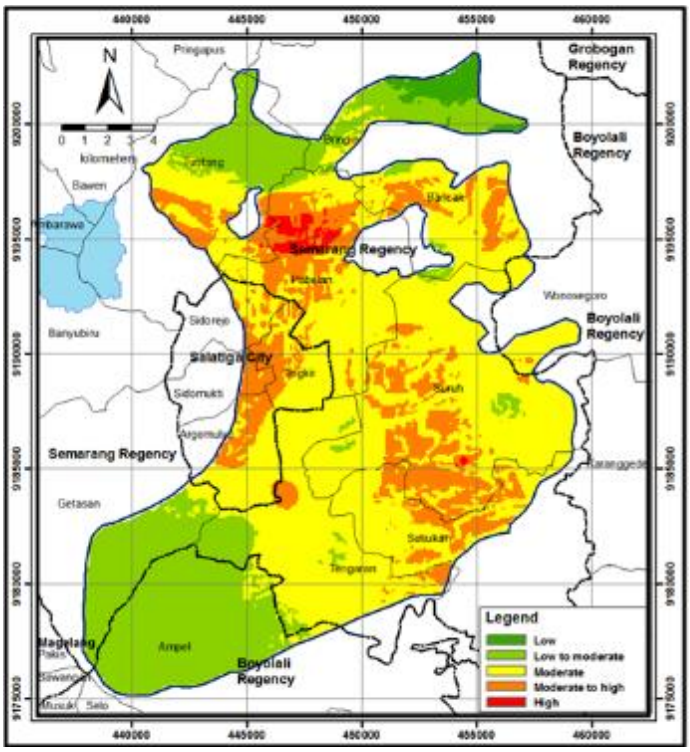

Figure 9. Vulnerability Map.

Table 9. The Vulnerability Class and the Distribution Area.

No	DRASTIC Index	Vulnerability Class	Characteristic [17]	Distribution Area
1	85 – 100	Low	Only vulnerable to conservative pollutants in the long term when continously and widely discharged or leached	Semarang Regency: The southern part of Bringin District, small part of the northern of Bancak District
2	101 – 120	Low to Moderate	Only vulnerable to conservative pollutants in the long term when continously and widely discharged or leached until Vulnerable to some pollutants but only when continously discharged or leached.	Semarang Regency The southern part of Getasan district, small part of the southern of Tengaran district, the northern part of Tuntang district, the southern part of Bringin district, small part of the northern of Bancak district Boyolali Regency : Ampel district
3	121 – 140	Moderate	Vulnerable to some pollutants but only when continously discharged or leached.	Semarang Regency Tuntang, Pabelan, Bancak, Suruh, Tengaran districts and small part of the southern of Bringin district. Boyolali Regency

No	DRASTIC Index	Vulnerability Class	Characteristic [17]	Distribution Area
				The small part of the western of Wonosegoro district Salatiga City Sidorejo, Tingkir, and Argomulyo districts
4	141 – 150	Moderate to high	Vulnerable to some pollutants but only when continously discharged or leached. Until vulnerable to many pollutants (except those strongly absorbed or readily transformed) in many pollutants scenarios.	Semarang Regency Tuntang, Pabelan, Bancak, Suruh, and Tengaran districts Salatiga City Sidorejo, Sidomukti, Tingkir, and Argomulyo districts
5	151 – 159	High	Vulnerable to many pollutants (except those strongly absorbed or readily transformed) in many pollutants scenarios.	Semarang Regency Most of the northern part of the Pabelan district and small part of the southern of Suruh district

Basically, the level of vulnerability in the study area are influenced by all the local hydrogeological factors. However, the most influential factor is the depth of groundwater level and rocks in the unsaturated (vadose) zone. Based on the groundwater vulnerability maps, land use zoning can be determined. In principle, the area with the high vulnerability of aquifers against contamination should be reserved for the low potency of land utilization, whereas in areas with low vulnerability against contamination can earmarked for land utilization with high potency of contamination, such as industrial activities, waste disposal and so on.

5. Conclusion

Based on the DRASTIC method analysis, the levels of groundwater vulnerability against contamination in Salatiga Groundwater Basin were classified into: Low, Low to Moderate, Moderate, Moderate to High, and High level. The high level of vulnerability zone was found in Pabelan District, Semarang Regency. The main factor affecting the high level of vulnerability zone was the very shallow depth to the water table, which was 0.6 – 1.5 meters depth from the local groundwater surface. The shallow position of groundwater table will cause contaminants to easily reach the groundwater, so that the potency of groundwater contamination in the area will be increased.

6. Acknowledgement

The authors wish to acknowledge PUSBINDIKLATREN BAPPENAS for funding this research as well as Zaky and Yusrizal from Geological Engineering Department, Diponegoro University for assisting in the field.

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