Groundwater Vulnerability Mapping in Muntilan and its Surrounding Area, Magelang Regency, Central Java, Indonesia

K Aribowo1, W Wilopo2,3,* and D H Barianto2,3

1Master program of Geological Engineering, Universitas Gadjah Mada, Jln. Grafika No. 2, Bulaksumur, Yogyakarta, 55281 Indonesia
2Departement of Geological Engineering, Universitas Gadjah Mada, Jln. Grafika No. 2, Bulaksumur, Yogyakarta, 55281 Indonesia
3Center for Disaster Mitigation and Technological Innovation (GAMA-InaTEK), Universitas Gadjah Mada, Jln. Grafika No. 2, Bulaksumur, Yogyakarta, 55281 Indonesia

*Corresponding author: wilopo_w@ugm.ac.id

Abstract. Groundwater resources are vital for residents in Muntilan Sub-District and its surrounding area in Central Java. The residents use groundwater for daily consumption by developing dug wells. Therefore, groundwater sources from contamination should be protected to guarantee sustainable groundwater use in this area. Groundwater vulnerability maps can be used as basic information to prevent groundwater contamination, land-use planning, and groundwater resources management. Therefore, this study aims to develop the groundwater vulnerability map in the Muntilan, Salam, Ngluwar Sub-Districts, Magelang Regency, Central Java. The vulnerability assessment used the DRASTIC method. The method has used the sum of the weighting of various parameters, including topography, net recharge, groundwater depth, the impact of the vadose zone, soil media, hydraulic conductivity of the aquifer, and aquifer media. The analysis results described that the DRASTIC Index (DI) value ranges from low to high levels, low levels, and the moderate level of vulnerability covers Muntilan sub-district and salam sub-district, while high levels of vulnerability are located in Muntilan, Ngluwar, and Salam Sub-Districts. Therefore, this vulnerability can be used for regional spatial planning and groundwater protection in the district.

Keywords: DRASTIC method, groundwater vulnerability, Muntilan.

1. Introduction
Regional development and population growth from year to year in Muntilan Sub-District and its surrounding area in Magelang Regency continue to increase. The increase in population results in increased groundwater needs for daily purposes and other activities related to agriculture and industry. Decreasing groundwater quality levels will make groundwater resources unable to function as primary needs for community life. Population growth will be followed by increasing groundwater use. As a result, groundwater quality can deteriorate due to human activities [1].
Groundwater is essential but is often misused due to a lack of understanding and good management. The main threats to groundwater arise from the steady increase in its use as population and per capita grows, irrigation, and chemical discharges to the ground surface [2].

Groundwater vulnerability measures the likelihood that pollution or contaminant will reach an aquifer [3]. A groundwater vulnerability map is a reliable tool to protect and manage groundwater and land resources. Groundwater vulnerability map gives information related to groundwater-protected areas, determines landfills location and wastewater treatment plants, and designs groundwater monitoring networks. [4]. Groundwater vulnerability map is an essential tool for evaluating the level of vulnerability and land use planning [5].

Over the past two decades, many intrinsic groundwater vulnerability mapping methodologies have been developed, such as the LeGrand method, GOD, DRASTIC, SINTACS, AVI, Hoelting [6]. The DRASTIC method with support by Geographical Information System (GIS) software was used in this study.

A hydrogeological map for the intrinsic vulnerability is produced with Raster analysis in GIS [4]. The study's objective is to determine groundwater vulnerability to pollution in Muntilan District and its surrounding area in Central Java. The study area is located in the Muntilan sub-district, Salam sub-district, and Ngluwar sub-district, a part of Magelang Regency, Central Java Province. The study area is approximately 82.68 km² area. It can be shown in Figure 1.

![Figure 1. Research location](image)

2. Material and Method
The investigation of groundwater vulnerability used the DRASTIC method. The DRASTIC model used seven parameters: D for depth to water level, R for net recharge, A for aquifer media, S for soil media,
T for topography, I for the impact of the vadose zone, and C for hydraulic conductivity of the aquifer [7]. The drastic index was calculated using Equation 1

$$
\text{DRASTIC Index} = D_R \cdot D_W + R_R \cdot R_W + A_R \cdot A_W + S_R \cdot S_W + T_R \cdot T_W + I_R \cdot I_W + C_R \cdot C_W \ldots \ldots (1)
$$

Where $W$ = weight, $R$ = rating, and $D$, $R$, $A$, $S$, $T$, $I$, and $C$ are seven parameters of the DRASTIC method. The rating of the parameters is shown in Table 1 until Table 7. The weight factor for $D_W = 5$, $R_W = 4$, $A_W = 3$, $S_W = 2$, $T_W = 1$, $I_W = 5$, $C_W = 3$. In this study, the ArcGIS software developed the maps and calculated the DRASTIC Index, as shown in Figure 2. The classification of the DRASTIC Index value is shown in Table 8.

![Figure 2. Overlay of DRASTIC parameters with ArcGIS [8]](image_url)

| Table 1. Depth to water table [7] | Table 2. Net Recharge [7] | Table 3. Aquifer Media [7] |
|----------------------------------|--------------------------|--------------------------|
| **Range (m)** | **Rating** | **Range (mm/a)** | **Rating** | **Range** | **Rating** |
| 0 – 1.524 | 10 | 0 – 50.8 | 1 | Karst limestone | 10 |
| 1.524 – 4.57 | 9 | 50.8 – 101.6 | 3 | basalt | 9 |
| 4.57 – 9.15 | 7 | 101.6 – 177.8 | 6 | Sand and gravel | 8 |
| 9.15 – 15.25 | 5 | 177.8 – 254 | 8 | Massive limestone | 6 |
| 15.25 – 22.87 | 3 | >254 | 9 | Massive sandstone | 6 |
| 22.87 – 30.5 | 2 | | | Limestone, shale sequences | 6 |
| >30.5 | 1 | | | Weathered metamorphic/igneous thin-bedded sandstone | 4 |
| | | | | Metamorphic/igneous | 3 |
| | | | | Massive shale | 2 |
Table 4. Soil Media [7]

| Range       | Rating |
|-------------|--------|
| Nonshrinking and non-agg | 1 |
| Clay        | 3 |
| Clay loam   | 4 |
| Silty loam  | 5 |
| Sandy loam  | 6 |
| Shrinking and/or arg. clay | 7 |
| Sand        | 9 |
| Gravel      | 10 |
| Thin or absent | 10 |

Table 5. Topography [7]

| Range (%) | Rating |
|------------|--------|
| >18        | 1 |
| 12 - 18    | 3 |
| 6 - 12     | 5 |
| 2 - 6      | 9 |
| 0 - 2      | 10 |

Table 6. Impact of Vadose Zone Media [7]

| Range       | Rating |
|-------------|--------|
| Karst limestone | 10 |
| Basalt      | 9     |
| Sand and gravel | 8 |
| Metamorphic/igneous | 4 |
| Sand and gravel with significant silt and clay | 6 |
| Bedded limestone, sandstone, shale | 6 |
| Sandstone   | 6     |
| Limestone   | 6     |
| Shale       | 3     |
| Silt/Clay   | 1     |

Table 7. Hydraulic Conductivity [7]

| Range (mm/d) | Rating |
|--------------|--------|
| 0.041 – 4.08 | 1 |
| 4.08 – 12.24 | 2 |
| 12.24 – 28.56| 4 |
| 28.56 – 40.80| 6 |
| 40.80 – 81.60| 8 |
| >81.6        | 10 |

Table 8. Classification of DRASTIC index value [9]

| DRASTIC index value | Corresponding vulnerability level |
|---------------------|----------------------------------|
| Higher than 199     | Very high                        |
| Between 146 and 199 | High                             |
| Between 120 and 145 | Moderate                         |
| Lower than 120      | Low                              |

3. Results and Discussion

3.1 Depth To Water Table (D)

Groundwater depth is measured from the ground surface to the groundwater table. This factor is essential because groundwater depth will affect the time it takes for contaminants to reach the groundwater table. Groundwater level depth was collected by measuring the resident's wells as many as 90 wells in March 2021. The depth measurement can be classified into four depth classes, as shown in Figure 3(a). The shallowest depth below the surface is 0.4 m. The depth to water table parameter weighs 5.

3.2 Net Recharge (R)

Rainwater with a certain amount that infiltrates into the soil and reaches the aquifer is called recharge. Rainwater absorbed into the soil through soil pores brings the contaminants vertically to the groundwater table and flows to the aquifer. The Recharge rate level parameter weights 4. Recharge Rate is affected by rainfall, evapotranspiration, and runoff. Rainfall data were collected from the Central Bureau of Statistics (BPS), the Public Works office of Magelang Regency, and Yogyakarta Special Province. The recharge zone is divided into one zone based on rainfall, evapotranspiration, and runoff calculations, as shown in Figure 3(b).

3.3 Aquifer Media (A)

The movement of contaminants in water-saturated rocks (aquifers) depends on the type of aquifer media because the role of aquifer media can control fluid movement. The aquifer media data are collected based on field identification and secondary data such as borehole data and subsurface interpretation by
the geoelectric method. Correlation from that data interpreted breccia as aquifer media, as shown in Figure 4(a). The Aquifer media level parameter weights 3.

![Image](https://via.placeholder.com/150)

**Figure 3.** (a) Depth of groundwater table map (b) Net recharge map

### 3.4 Soil Media (S)
Soil media impact recharge because recharge can infiltrate the soil and bring contaminants into the aquifer or vadose zone. Therefore, the Soil media level parameter weights 2. Soil media was obtained by sieving analysis of 34 samples of soil. From the sieve analysis, soil media can be divided into the sand and sandy loam, as shown in Figure 4 (b).

### 3.5 Topography (T)
The length of time water flow is in one area can be affected by topography. The slope or topography of the research area was developed based on digital elevation model data. It weighs 1. The slope can be divided into five classes, as shown in Figure 4 (c).

### 3.6 Impact of the Vadose Zone Media (I)
The vadose zone is an unsaturated layer above the groundwater table [7]. The characteristics of the material attenuation above the groundwater table are identified from the media type in the vadose zone. [7]. The weights parameter for the impact of a vadose zone is 5. The vadose zone data were collected based on field identification and secondary data such as drilling and subsurface estimation using the geoelectric method. It shows that lahar sediment and andesite are the vadose zone materials, as shown in Figure 4 (d).
Figure 4. (a) Aquifer map (b) Soil map (c) Topography map (d) Vadose zone map
3.7 Hydraulic Conductivity (C)
Hydraulic conductivity is the ability of an aquifer to transmit groundwater water, which then controls flow rate with a specific hydraulic gradient [7]. The hydraulic conductivity weights 3. The hydraulic conductivity data were calculated from the pumping test data belong to the Ministry of Public Works and Housing, as shown in Figure 5(a).

3.8 Groundwater Vulnerability Assessment using the DRASTIC method
Figure 5 (b) presents the groundwater vulnerability in the Muntilan, Salam, and Ngluwar sub-district. The DRASTIC index (DI) value was divided into three classes, low vulnerability (<120), moderate vulnerability (120 - 145), and high vulnerability (146 - 199). The distribution of the low vulnerability value was in the Muntilan sub-district and Salam sub-district. Moderate vulnerability value was in the Muntilan sub-district, Salam sub-district, and a little bit in the Ngluwar sub-district. Finally, the high vulnerability value was in the Muntilan sub-district, salam sub-district, and Ngluwar sub-district.

3.9 Validation for groundwater vulnerability map
The results of the groundwater vulnerability map can be verified by evaluating the chemical concentration in groundwater, such as nitrate concentration [8]. Nitrate has become one of the main factors indicating a worsening trend of groundwater quality [10]. Chemical measurement for nitrate from groundwater samples is presented in Table 9. Nitrate values have a range from 0.16 mg/L until 18.18 mg/L.

Validation of the DRASTIC method results can be obtained from the correlation between the nitrate concentration values of 30 shallow groundwater samples and the value of the groundwater vulnerability index. Shallow groundwater samples were collected in April 2021. Comparison of Figures 5(b) and 6 explains that nitrate concentration and groundwater vulnerability class do not correlate well. It could be
due to the nitrate load on groundwater. The area with low population density will give low nitrate load, which the growing population will be followed by increasing nitrate load. The maximum tolerable nitrate value for human health is 50 mg/L based on the World Health Organization. Anthropogenic contaminants are indicated when the nitrate value in groundwater is higher than 10 mg/L [8].

Table 9. Chemical measurement samples in resident well

| Sub-District | Location       | Village   | Samples Code | Coordinate | Groundwater Table (m) | Nitrate (mg/L) |
|--------------|----------------|-----------|--------------|------------|-----------------------|----------------|
| Ngluwar      | Karangtalun    | Well - 1  | 419340       | 9152780    | 3.3                   | 1.65           |
| Ngluwar      | Bligo          | Well - 8  | 419668       | 9149589    | 1.7                   | 1.61           |
| Ngluwar      | Bligo          | Well - 13 | 420169       | 9149226    | 1.8                   | 1.45           |
| Ngluwar      | Pakunden       | Well - 15 | 419864       | 9151734    | 1.0                   | 0.16           |
| Ngluwar      | Pakunden       | Well - 19 | 420621       | 9152507    | 2.6                   | 1.16           |
| Ngluwar      | Somokaton      | Well - 21 | 422144       | 9153414    | 2.9                   | 1.29           |
| Ngluwar      | Jamuskauman    | Well - 24 | 420614       | 9154651    | 3.5                   | 1.42           |
| Ngluwar      | Blongkeng      | Well - 25 | 417605       | 9155725    | 1.7                   | 6.57           |
| Ngluwar      | Plosogede      | Well - 27 | 419146       | 9155189    | 4.6                   | 5.97           |
| Salam        | Mantingan      | Well - 30 | 422608       | 9154936    | 3.1                   | 0.89           |
| Salam        | Salam          | Well - 33 | 424524       | 9155117    | 1.3                   | 7.60           |
| Salam        | Salam          | Well - 34 | 425852       | 9155782    | 0.6                   | 6.78           |
| Muntilan     | Sokorini       | Well - 36 | 416863       | 9157352    | 3.9                   | 5.01           |
| Salam        | Sirahan        | Well - 40 | 418943       | 9157370    | 1.5                   | 0.12           |
| Salam        | Transgede      | Well - 42 | 421330       | 9157349    | 5.0                   | 4.45           |
| Salam        | Tirta          | Well - 43 | 422759       | 9157099    | 1.9                   | 1.01           |
| Salam        | Sucen          | Well - 45 | 425300       | 9157179    | 0.4                   | 5.75           |
| Salam        | Sucen          | Well - 47 | 426000       | 9156808    | 3.5                   | 4.90           |
| Muntilan     | Adikarto       | Well - 51 | 417228       | 9159280    | 2.4                   | 0.48           |
| Muntilan     | Ngawen         | Well - 55 | 418712       | 9159115    | 3.9                   | 0.68           |
| Salam        | Seloboro       | Well - 56 | 420786       | 9159158    | 7.3                   | 9.78           |
| Salam        | Jumoyo         | Well - 60 | 422671       | 9158823    | 2.8                   | 11.73          |
| Salam        | Jumoyo         | Well - 62 | 424058       | 9159163    | 5.0                   | 18.18          |
| Muntilan     | Gunungpring    | Well - 70 | 420898       | 9161040    | 1.4                   | 0.02           |
| Muntilan     | Keji           | Well - 74 | 419078       | 9161051    | 7.8                   | 6.68           |
| Muntilan     | Sedayu         | Well - 77 | 422126       | 9163113    | 2.3                   | 10.38          |
| Muntilan     | Gondosuli      | Well - 82 | 422588       | 9164635    | 1.0                   | 3.90           |
| Muntilan     | Gondosuli      | Well - 84 | 421338       | 9164205    | 4.3                   | 6.05           |
| Muntilan     | Tamanagung     | Well - 86 | 420880       | 9162628    | 2.6                   | 2.80           |
| Muntilan     | Tamanagung     | Well - 89 | 419362       | 9162198    | 1.1                   | 3.26           |
4. Conclusion
The DRASTIC method with support by GIS software was used to assess the potential aquifer to the contamination. The drastic index in Muntilan Sub-District and its surrounding area in Central Java is divided into three classes, low vulnerability with DI index below 120, moderate vulnerability with DI index 120 – 145, and high vulnerability with DI index 145 – 199. The low and moderate vulnerabilities cover the Muntilan sub-district and salam sub-district, while high vulnerabilities are located in Muntilan, Ngluwar, and Salam Sub-Districts. The nitrate concentration in groundwater did not show a good correlation with the groundwater vulnerability map. It is due to different nitrate loads in each area. Therefore, the Muntilan sub-district, Salam sub-district, and Ngluwar sub-district still have to pay attention to groundwater vulnerability in regional development. Consequently, it is recommended to continue using organic fertilizers for agriculture and prepare a communal-based sanitation plan. Suppose there is an industry in this area in the future. In that case, the government must prepare regulations regarding waste management so that industrial activities do not pollute groundwater.

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